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Deutsches Institut für Entwicklungspolitik

German Development Institute

Discussion Paper 28/2014

Green Industrial Policy

Managing Transformation under Uncertainty

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Bonn 2014

Discussion Paper / Deutsches Institut für Entwicklungspolitik
ISSN 1860-0441

Die deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d-nb.de abrufbar.

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data is available in the Internet at http://dnb.d-nb.de.

ISBN 978-3-88985-653-1

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Acknowledgements

We are grateful to Michele Clara, Dirk Messner, Philipp Neuerburg, Hubert Schmitz and Imme Scholz for reviewing an earlier draft of this paper and for providing helpful comments and suggestions. Of course, all remaining inaccuracies and errors are entirely ours.

Bonn, October 2014

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Abbreviations

ADB	Asian Development Bank
BEE	Bureau of Energy Efficiency (India)
BEV	Battery-electric vehicles
BMU	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, Germany)
BRICS	Brazil, Russia, India, China, South Africa
CCS	Carbon capture and storage
CEO	Chief executive officer
CFCs	Chlorofluorocarbons
CO_2	Carbon dioxide
COP 21	21st Conference of the Parties on Climate Change
DAX	Deutscher Aktienindex (German Stock Index)
ETS	Emission Trading System
EU	European Union
FCEV	Fuel cell electric vehicle
FiT	Feed-in tariffs
Gb	Giga-barrel
GDF	Gaz de France (Gas of France)
GDP	Gross domestic product
g/km	Gram per kilometre
gCO_2/km	Gram of carbon dioxide per kilometre
GW	Gigawatt
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
IEA	International Energy Agency
IGES	Institute for Global Environmental Strategies
IISD	International Institute for Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hour
LDCs	Least developed countries
LED	Light-emitting diode
MIT	Massachusetts Institute of Technology
MW/km2	Megawatts per square kilometre
NPE	Nationale Plattform Elektromobilität (National Platform for Electromobility)
NSR	North Sea Region
OECD	Organisation for Economic Co-operation and Development
R&D	Research and development
REEV	Range extended electric vehicle
RWE	Rheinisch-Westfälisches Elektrizitätswerk AG

SUV	Sport utility vehicle
UNCSD	United Nations Conference on Sustainable Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
UNU	United Nations University
US	United States
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Advisory Council on Global Change)
WEF	World Economic Forum
WHO	World Health Organisation

Summary

The paper in a nutshell: In this paper, we present the normative concept of green industrial policy, which we define as encompassing any policy measure aimed at aligning the structure of a country's economy with the needs of sustainable development within established planetary boundaries. We elaborate on why we need green industrial policy, how it differs from conventional industrial policy, why it is faced with significantly bigger challenges, and how these can be met.

What and how we produce and consume is largely shaped by markets. However, markets fail to solve many of the environmental challenges we are facing. Therefore, we need governments to intervene, thus reclaiming the primacy of public policy in setting and implementing societal objectives. While safeguarding the sustainability of human life on our planet makes green industrial policy a highly normative undertaking, the economic case for green industrial policy is strong as well – the success stories of such 'green' frontrunners as Germany and Denmark demonstrate the competitiveness potential of the new technologies. However, as shown by decades of discussion on industrial policy, government intervention almost invariably brings about risks of political capture and government failure. Green industrial policy is thus not only governed by ethical norms, but also by politics. The risks of failure are magnified by the urgency and scale of today's global environmental challenges, requiring particularly bold, comprehensive and well-orchestrated government intervention under high uncertainty. By highlighting lessons learned from practical cases of both success and failure, we show how these risks can be, and have been, managed. In particular, we submit that a broad-based social vision and contract need to be forged – supported by change coalitions and coupled with policy process safeguards, openness to policy learning, and an alignment of green industrial policies with market mechanisms.

Green industrial policy is a highly normative undertaking with societal goals and ethical imperatives as its essential foundation (Section 2). We argue that economic markets are a social construct with flexible and changing boundaries. Markets provide an efficient allocation mechanism (a *process* norm) that needs to be guided by, and subordinated to, agreed societal *outcome* norms defining desirable development objectives in terms of environmental sustainability and distributional fairness. Recalling the long-standing discourse on economics and ethics, we stress that the triple challenge of maintaining economic growth, avoiding environmental disasters and keeping inequality and poverty levels in check calls for more than just improving allocative efficiency through the internalisation of environmental costs. While the latter is necessary, it cannot, in and by itself, generate a development path that is aligned with broader societal goals.

In the paper's main section, Section 3, we elaborate on the distinctive features of *green* industrial policy. As such, we consider (a) the existence of pervasive market failures, (b) the need to deal with high levels of uncertainty within long-time horizons, as well as the challenge of (c) creating new and (d) disrupting old pathways.

(a) *Responding to pervasive market failures*: We present a typology of market failures and highlight those that are particularly relevant from the angle of environmental policy goals (externalities, coordination failures and public goods). While acknowledging the importance of 'getting the prices right', we emphasise the need to go beyond pricing

instruments. This is necessary due to political implementation challenges, the existence of other market imperfections (such as low price elasticities and principal-agent problems) and above all, the urgency of action and thus the need to control the adjustment period of the green transformation.

This sub-section contains Boxes on: coordination failures in moving towards electric mobility systems, and attempts to overcome them; market-based green industrial policy instruments; and policy harmonisation challenges in the case of feed-in tariffs and emission trading systems.

(b) *Addressing high uncertainty and long-time horizons*: We argue that the exceedingly high level of uncertainty and the long causal chains are defining features of green industrial policy. They originate from a variety of factors, including the dynamics of complex ecosystems and the scientific modelling of climate change, the unknown technical feasibility and commercial applicability of new transformative technologies, the unpredictability of global policy approaches, and the risks surrounding the impact of innovative policy instruments.

This sub-section contains Boxes on: the unknown potential of carbon capture and storage technologies; and the German energy transition as a long-term national transformation project.

(c) *Creating new pathways*: Against the reality of path dependency, massive carbon lock-in effects and entrenched behavioural patterns favouring unsustainable production and consumption, green industrial policy must create new sustainable development pathways. We emphasise the policy dilemma of having to nurture new transformative technologies (not just conventional industrial sectors) within a process of experimentation and discovery while also having to push for their commercial scalability and uptake. This calls for well-calibrated decisions and risk-taking coupled with efforts to overcome a variety of behavioural biases. In this context, we underline the importance of collective and consultative priority-setting as being distinct from the misleading notion of ‘picking winners’. Furthermore, we highlight the role of policy-induced lead markets as drivers of innovation.

This sub-section contains Boxes on: the approach of strategic niche management; the circular economy concept; evidence from behavioural sciences on decision-making; the Indian experience of using norms and standards in promoting green consumption; the promotion of efficiency technologies in Germany; and the challenge of dealing with the existing stock of ‘dirty’ technologies.

(d) *Disrupting old pathways*: We emphasise that in addition to building up a new green economic development pillar, the dismantling of the existing brown pillar of polluting industries will also require creative policy approaches. Investment-encouraging incentives need to be complemented by investment-discouraging incentives. We elaborate this challenge by drawing attention to stranded assets and more specifically, to the topical issue of ‘unburnable carbon’.

This sub-section contains Boxes on: the Norwegian Oil Fund and German RWE as illustrations of how existing carbon-based assets are challenged; the Montreal Protocol as a successful international agreement to phase out a set of harmful technologies; and the approach taken by the European Union (EU) automotive fleet emission standards.

In Section 4, we address the political economy of transformation and put the management of policy-induced rents at centre stage. Policy rents (originating, for instance, from politically set prices, preferential loans or subsidised investments) have the potential to become strong drivers of innovation yet may also be politically captured. This risk is particularly pronounced in the case of green incentives in view of their pervasiveness, that is, covering long periods and the entire economy. We suggest approaches to curb this risk in Section 5.

This section contains Boxes on: political capture elements in the electricity surcharge in Germany; and the continued reality of fossil fuel subsidies.

In Section 5, we consider ways forward to make transformative change happen. We stress the need for a broad societal consensus on the direction of change and its main long-term objectives and on underpinning the green transformation with change coalitions that can be built across different groups of stakeholders having diverse motivations and goals. We also emphasise the importance of policy-learning mechanisms both over time and across countries and the desirability of introducing market-based, competitive elements into the policy process.

This section contains Boxes on: the importance of co-benefits of green growth in developing countries; general concepts of policy-learning; emerging economy approaches to reforming feed-in tariffs for renewable energy; and the specific case of the Indian 'solar mission' programme.

Finally, in Section 6, we summarise our main arguments and stress that the Herculean task of bringing about a green transformation – a fundamentally new growth model, sustainable patterns of behaviour, and radical technological innovation – must build on acceptance and support by society at large. This in turn is critically related to the distributional impact of green industrial policy, in particular in terms of how it affects the balance between green sunrise and brown sunset industries, as well as the asset and income distribution of different population groups.

"The best way to predict your future is to create it"
(Peter F. Drucker)

1 Introduction: planetary boundaries and the next 'great transformation'

The looming danger of catastrophic global warming and other aspects of environmental mismanagement – from the depletion of aquifers and ocean acidification to biodiversity loss – have given rise to concerns about economic development exceeding the earth's carrying capacity, that is, running against planetary boundaries and exiting our 'safe operating space' (Rockström et al. 2009). In response, natural and social sciences are seeking to align their research agendas, and attempts are being made to establish 'planetary economics' (Grubb / Hourcade / Neuhoff 2014) as a new discipline. Significantly, the Fifth IPCC Assessment Report (Working Group III) devotes, for the first time, a whole chapter to 'social, economic and ethical concepts and methods' (IPCC 2014).

Likewise, in one of its most recent flagship reports (WBGU 2011), the German Advisory Council on Global Change argues that the transition towards a low-carbon, sustainable global economic system constitutes a radical transformation – on par indeed with the two great transformations (Polanyi 1944) mankind has encountered so far: the pre-historic Neolithic settlement and the transformation of agrarian into industrial societies (see also Leggewie / Messner 2012).[1] At the same time, the report also points to an important distinction in that the first two great transformations were natural, evolutionary processes while the shift towards a new sustainability paradigm is predominantly a planned, policy-induced process. Furthermore, based on a broad consensus in climate science, this is the first transformation with a deadline (Schmitz / Johnson / Altenburg 2013) – lest irreversible ecological tipping points be ignored at our own peril.

At the core of this necessary transformation towards sustainable practices is a profound renovation of economic structures, technologies and institutions. Entire economic sub-systems need to be deeply rethought and redesigned when it comes to decarbonising, for instance, the energy system or the way transport is organised. Managing such structural transformation is the domain of industrial policy. Against this backdrop – and alongside mushrooming, and often ill-defined, notions of green growth and a green economy – the term 'green industrial policy' is rapidly gaining currency. In recent years, it has found its way into globally negotiated commitments (UNCSD 2012) and is being increasingly used by economic development and policy researchers (Rodrik 2013; Schmitz / Johnson / Altenburg 2013; Johnson / Altenburg / Schmitz 2014; Pegels 2014a) as well as by international organisations (for the World Bank: Hallegatte / Fay / Vogt-Schilb 2013; for IISD: Schwarzer 2013; Lütkenhorst / Pegels 2014; UNIDO 2011a).

The present paper examines the key characteristics of green industrial policy as being distinct from a more conventional understanding of industrial policy. It identifies the

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1 It is intriguing to note that much of the current literature on a forthcoming new industrial revolution seems to be path-dependent itself (see Sub-section 3.3) and is addressing issues such as the spread of globalisation, pervasive information technologies or 3-D printing technologies (Andersen 2012; Marsh 2012; Dosi / Galambos 2013) rather than the sustainability revolution. In contrast, the latter is emphasised, from the angle of decentralised energy systems, by Rifkin (2011).

defining features of green industrial policy in terms of its rationale and legitimation, its conceptual characteristics and its implementation challenges.

The paper is organised as follows. In Section 2, we address the normative content of green industrial policy by drawing on the long-standing, more general debate on economics and ethics. Section 3 is devoted to exploring the various distinctive features of green industrial policy and, in doing so, the section focuses on economic and technological considerations. As compared to conventional industrial policy concepts, these features may in some cases involve differences in degree rather than in nature yet we believe that in essence we are dealing with genuine quantum leaps. Section 4 adopts a process perspective and addresses the political economy of the green transformation challenge. Section 5 presents the key elements for a way forward towards managing the green transformation. The main conclusions of our paper are pulled together in Section 6. Throughout the paper we have included text boxes illustrating our general arguments with concrete examples of how green industrial policy challenges play out in reality and how policymakers are trying to cope with them.

While this paper also touches upon the need to align the green and the inclusive development dimensions – and indeed argues that disregarding the latter will put the former at risk – its main focus clearly remains on providing an overview of the key challenges associated with the pursuit of policies to promote green development.

2 The primacy of social goals over markets: raising the normative stakes

The WBGU Report quoted above calls for a "proactive state" seized with the "ethical imperative" to bring about the required transformation through determining long-term priorities and underpinning them with clear policy signals (WBGU 2011, 1–2).

Against this backdrop, and very much in the same spirit, we define industrial policy as any intentional measure taken by public authorities to steer the structure of an economy into a desired direction. By extension, *green* industrial policy encompasses any policy measure aimed at aligning the structure of a country's economy with the needs of sustainable development within established planetary boundaries – both in terms of the absorption capacity of ecosystems and the availability of natural resources. This definition extends beyond more narrow notions of green industrial policy, which focus on the promotion of low-carbon fossil fuel alternatives (Karp / Stevenson 2012) or the nurturing and promotion of industrial sectors that produce green technologies and goods (Cosbey 2013).

From externalities to societal goals

Let us briefly hark back to the general discourse on industrial policy. Clearly, we are not interested in regurgitating a meanwhile well-known debate with its business cycle of acceptance, scepticism, denial and lately, renaissance (Altenburg 2011; Lauridsen 2010; Lin / Chang 2009; Warwick 2013; UNIDO 2011b). However, it is worth mentioning that most of the arguments used to justify industrial policy evolve around various types of market failures, ranging from information shortcomings to technological spillovers, imperfect capital markets, uncoordinated investment decisions, systemic infrastructure requirements and externalities that drive a wedge between private and social costs and benefits. Hence, so the argument goes, policy interventions are needed to take corrective action.

This market failure-based *raison d'être* of industrial policy is a necessary first step, and we will revert to it in the first part of Section 3. However, the justification for industrial policy, and green industrial policy in particular, goes beyond correcting market failure. The concept of market failure is based on a neoclassical paradigm, benchmarking the outcome of existing market processes against those of ideal markets in which 'homo economicus' acts rationally in a competitive space with full information, instant adjustment speed and absence of externalities. But even if markets were to function according to this paradigm, the question must be asked whether they would automatically create what society at large would consider the best social outcome. Here, issues of societal norms and values come in, which may differ considerably across time and space. What outcome societies consider optimal in a given historical and local context needs to be politically negotiated and agreed; assuming one abstract optimal outcome regardless of social structures and preferences is highly unrealistic. Hence, we submit that the rationale and legitimation of industrial policy need to be framed in a broader context.

Let us consider just two illustrative examples:

- A perfectly functioning market will generate a functional income distribution that responds to relative availabilities and prices of labour and capital as the main production factors. This income distribution may or may not be socially acceptable. In addition to the fundamental imperative of fairness, numerous further assessment dimensions will have to be factored in: regional, gender, ethnic, age, cultural norms, etc. Societies may, for example, wish to maintain a regionally balanced distribution of economic activities even when this implies sacrificing some allocative efficiency.
- A perfectly functioning market will select technologies (for example, within a quota system for renewable electricity generation) that are most cost-efficient as assessed from the perspective of today's prices and their anticipated future trends. However, this does not account for possible societal preferences in favour of long-term technology diversification with a view to reducing future risks and dependencies in a broader national perspective.

In short: The logic of market coordination and allocation of resources represents a partial, economic logic that – within a hierarchical perspective – is subordinate to the realm of social norms and goals. Markets are all about allocative efficiency – and in this domain, they may arguably be the most effective coordination mechanism; however, additional societal preferences related to distribution, fairness, equal opportunities, respect for human capabilities, risk management, and political prudence need to be factored in. The outcome of market processes may meet efficiency standards. Yet, this must not be equated with their societal acceptability. Or, put differently: markets represent a *process norm,* which must be subjected to *outcome norms* in terms of what a society considers as both necessary and desirable. For the latter assessment, non-market institutions (from informal social networks and non-profit community services to elected governments) need to assume responsibility by going beyond Pareto optimality as a framework and monetary demand as a yardstick (Nussbaum 2011). This also requires going beyond preferences of distinct groups of stakeholders by factoring in protection of species, biodiversity and livelihoods, which do not have a voice in market processes.

Furthermore, it bears mention that the market mechanism itself is a social construct. Its boundaries are set within historical contexts and modified by social conventions. As such, these have changed significantly over time – as exemplified by the gradually tightening introduction of labour and health regulations (Chang 2001; Chang 2010). Also, social conventions are bound to further evolve, particularly in developing economies, which almost by definition are characterised by a fuzzy and moving borderline separating their market and governance structures (Cimoli et al. 2009, 21). While the global community has adopted 'rules of the game' banning slave trade and other forms of human trafficking, many countries still allow the crudest forms of environmental damage to happen, to travel down rivers and to cross borders. However, the dividing lines between responsible, irresponsible and illegal behaviour are man-made and can be redrawn. At the same time, it needs to be recognised that *"markets are not mere mechanisms. They embody certain norms. They presuppose – and promote – certain ways of valuing the goods being exchanged"* (Sandel 2012, 64).

In this context, it is noteworthy that in Stiglitz's early plea for moving beyond the Washington Consensus (Stiglitz 1998), he argued strongly for economic policy to move towards 'broader goals' and address the multiple trade-offs that need to inform a socially relevant decision-making process – with environmental technologies being one of the examples selected.

Economics and ethics

The conceptualisation and positioning of economics in the treacherous space between a positive (that is, allegedly value-free) science and a normative 'moral science' has shaped methodological debates among economists, social scientists and philosophers for centuries. In particular, the evolution of welfare economics from its original utilitarian philosophical foundation into a highly technical discipline has marked this debate. At the same time, in the harsh opinion of Boulding:

> *Welfare economics ... has been a failure, though a reasonably glorious one ... Many, if not most, economists accept the Pareto optimum as almost self-evident. Nevertheless, it rests on an extremely shaky foundation of ethical propositions ... It assumes selfishness ... such that it makes no difference to me whether I perceive you as either better off or worse off. Anything less descriptive of the human condition can hardly be imagined* (Boulding 1969, 5–6).

Value judgments thus can (and do) easily enter the realm of what is often portrayed as a technical, value-free economic analysis. A telling example are seemingly technical assumptions about discount rates, that is, introducing a mechanism into long-term modelling exercises that (de-)values future costs and benefits as compared to those occurring today. Any assumed discount rate is indeed a technically couched (i.e. disguised) value judgment built into policy advice. Famously, in the debate about climate change, two seminal studies (Nordhaus 1994; Stern et al. 2007) work with discount rates of 6.0% and 1.4%, respectively, thus taking radically different views on the present value of costs and benefits impacting future generations (Broome 2008). Indeed, it has been demonstrated that the drastically differing policy recommendations derived from both studies can be explained almost entirely by the diverging discount rate assumptions used (Sunstein / Weisbach 2008).

Similarly, and generally noticed to a lesser extent, the deeply entrenched approach of measuring national welfare through the GDP is based on hidden value judgments. While these are not of an intergenerational nature, the fundamental assumption is that each monetary unit has the same value regardless of whether it is earned and spent by a billionaire businessman or a person living in abject poverty. This example should suffice to dispel the notion that economic efficiency and growth objectives are of a technical nature while distributional objectives are about value judgments. In reality, both spaces are closely intertwined and the *"tendency to separate efficiency from ethics"* (Crespo 1998, 201) can hardly be justified (see also Hausman / McPherson 1993).

Thus, one essential meeting point of economics and ethics has always been the question of whether or not economic efficiency yields results that from a broader societal and moral perspective can be considered as fair or just. In more technical terms, this is the debate around the distribution of goods and services, the absolute and relative incidence of poverty and the prevailing income inequality levels that result from market-based competitive allocation processes. In development economics, the controversy around inequality-inducing growth dynamics (as advocated by Hirschman's theory of unbalanced growth (1958) and epitomised by the Kuznets-curve) and subsequent approaches arguing for redistribution with growth (Chenery et al. 1974) and the priority fulfilment of basic human needs (Streeten 1981) have been iconic concepts in this domain.

In parallel, concerns about the earth's limited endowment with natural resources and limited absorptive capacity for public bads like pollution, triggered a new breed of global modelling exercises (Meadows et al. 1972, 'Limits of growth') and the emergence of ecological steady-state economic theories (Daly 1977). More recently, mounting concerns about various types of planetary boundaries and the ultimate catastrophe possibly following from global climate change have lent renewed urgency to environmental and resource economics.

There seems to be a strange paradox at play: While over decades a fierce debate has emphasised the normative implications of *positive* economics and the latter's misguided attempts to claim value-free territory, today we witness *normative* economics (dealing with policy prescriptions) itself trying to steer clear of values and norms and to find a foundation in *positive* market failure reasoning. In the same vein, the ongoing debate on green transformation and green policies is primarily couched in Pigouvian terms (removing externalities to increase allocative efficiency) or at best in Schumpeterian terms (creative destruction boosting technological innovation) yet rarely with reference to societal norms and objectives.[2]

We would argue that the normative content of green industrial policy is particularly high and pronounced. Essentially, it involves an exceedingly long-term transformation that is global in nature, requires the adoption of sustainability norms and standards for both production and consumption and has implications for both intra- und inter-generational distribution and equity. All the more so as irreversible tipping points of instability are not the monopoly of ecological systems.

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2 This applies to much of the economics literature, not to broader research approaches dealing with transformative change and innovation systems (see, for instance, WBGU 2011; Grin / Rotmans / Schot 2010). Notably, also the World Bank calls for *"framing green policies as a way to reach an ambitious and positive social goal"* (World Bank 2012, 19).

In view of widely rising levels of income inequality (not only for emerging economies but also for developed economies; OECD 2011), the danger of reaching also social tipping points is real. Indeed, in the 2013 Global Risks Report of the World Economic Forum, severe income disparity is identified as the premier global risk factor – as perceived by more than 1,000 experts from industry, government, civil society and academia (WEF 2013). Against this backdrop, the triple challenge of maintaining economic growth, avoiding environmental disasters and keeping inequality and poverty levels in check, namely to shape a green and inclusive future, is the defining element of the current global policy agenda.

However, in stark contrast to the need to bring various strands of economic policy research more closely together, there remains a noticeable gap between much of mainstream development economics on the one hand and research with an explicit sustainability focus on the other. While issues of factor costs, economic growth and trade dominate the former, it is the scarcity and waste of resources as well as the environmental impact of their exploitation that are emphasised in the latter. To date, we encounter high-profile publications by leading development economists without the slightest consideration of the sustainability dimension (see for instance Lin 2012; Chang / Grabel 2014; Salazar-Xirinachs / Nübler / Kozul-Wright 2014) – despite the promising prospect of sustainable development serving as a platform *"that could also help the field of economics itself reconnect with the physical basis of economic systems"* (Grubb / Hourcade / Neuhoff 2014, 424).

3 Distinctive features of green industrial policy

After having highlighted the rationale for (green) industrial policy, we now turn to its key characteristics and distinctive features, which – when seen in conjunction – demonstrate the exceedingly complex and demanding task faced by policy interventions aimed at a green transformation of current development trajectories. In a highly aggregated and stylised perspective, we distinguish four key challenges facing green industrial policy, which will be conceptualised and illustrated in this chapter:

1. Responding to pervasive market failures;
2. Addressing high uncertainty and long-time horizons;
3. Creating new pathways;
4. Disrupting old pathways.

3.1 Responding to pervasive market failures

It is stating the obvious that the production of environment-friendly ('green') goods and services as well as the avoidance and mitigation of environmental bads (such as pollution, waste, reduced biodiversity, climate change) are faced with a variety of market failures. Ultimately, as Stern famously put it, climate change is 'the biggest market failure the world has ever seen' (Stern et al. 2007). No surprise then that environmental economics is largely about how best to address and overcome various types of failing markets.

Types of market failures

In view of our focus on the real world challenges of green industrial policy, we will not endeavour to review the well-established literature on market failures. In essence, the typologies offered may differ in detail but can be reasonably summed up as has been done in Figure 1. Here, the market failures highlighted in grey deserve special attention from the vantage point of environmental policy goals and are thus addressed below.

Figure 1: Typology of market failures[3]

Main types of market failures				
Imperfect competition	***Asymmetric information***	***Coordination failures***	***Public goods***	***Externalities***
Market power resulting from non-atomistic structures and collusive behaviour	Superior information of some market actors (mostly on the supply side)	Obtainable benefits are not being reaped due to lack of coordinated action	Goods that are non-excludable and non-rival in consumption	Deviation between private and social costs and benefits
		Crucial for creating new and disrupting old techno-economic pathways	**Most severe in case of climate change mitigation suffering from 'free-riding'**	**Pervasive in environmental pollution, waste management and natural resource use**

Source: Authors

Coordination failures: Less straightforward than externalities, the failure to coordinate complementary activities can originate from lacking information and/or lacking trust among economic actors and may lead to foregone benefits for all parties concerned (as in the notorious 'Prisoners' Dilemma'). When changes in a society's basic techno-economic trajectory are necessary, when old pathways need to be broken down and replaced by new ones, effective coordination assumes highest importance: between producers of complementary goods, between new production modes and related infrastructure investments as well as between a changing portfolio of goods and changing consumer preferences (see Box 1).

Public goods: Unlike private goods, public goods are characterised by 'open access' (nobody can be excluded from the consumption of goods like the climate, national security or stable financial markets) and 'non-rivalry' (my consumption of fresh air does not compete with yours). For this paper, global public goods (Kaul et al. 1999), that is, public goods with universal outreach, are of particular importance. While in the sphere of the environment many global public goods come to mind (such as biodiversity and the earth's ozone layer), the earth's climate is at truly planetary scale and deserves special attention from the perspective of the indispensable low-carbon transformation.

3 Bounded rationality and behavioural biases, such as endowment effects (higher valuation of goods currently owned), excessive discounting of future gains, loss aversion and other forms of intuitive decision-making (Kahneman 2003) could also be considered as a market failure. However, if these phenomena determine human behaviour as such, they will also shape policy design and implementation decisions, and generally the behaviour of actors within different types of institutional settings. Hence, bounded rationality, while being of great importance and impact, is pervasive and does not constitute a genuine market failure.

Externalities: Examples abound and range from upstream river pollution affecting downstream residents and enterprises to the dumping of toxic waste, air pollution from coal-fired power plants, insufficient pricing of nuclear waste disposal or the socialisation of infrastructure costs originating from private transport (leisure cars and commercial trucks alike).

Box 1: Dealing with coordination failure in the transition to new systems: the case of electric mobility

The transition from our current road transport technologies to electric mobility illustrates the importance of coordination failure. Battery-electric vehicles (BEV) are potentially a low-carbon alternative to vehicles powered by internal combustion engines (ICE) – but only if the electricity that is used to charge their batteries comes from an energy system that uses no or few fossil fuel-based power plants (in the United States and China, for example, using the current national power mix would *increase* the emissions per vehicle). Electric vehicles can also contribute to clean air in urban agglomerations, because they produce no local emissions, and they do not make any noise.

Although many countries have set up ambitious programmes to support the shift from ICE to BEV, electric vehicle sales are still very low. This has several reasons: batteries are expensive; the driving range per battery load is limited; and the public charging infrastructure is not yet developed. To promote electric mobility, it is thus necessary to improve technologies, especially the performance of batteries in order to bring down unit costs and increase the driving range. At the same time, a charging infrastructure needs to be built up and its technical standards – for example, the type of plugs – need to be harmonised across countries. Consumers are unlikely to buy many electric vehicles until these problems are sorted out; carmakers will not produce unless consumer demand allows for economies of scale in production; and operators of charging stations will not invest in infrastructure as long as there are few electric vehicles on the road. To deal with such 'hen and egg' problems, policymakers need to create incentives in a coordinated way to ensure progress on all fronts *simultaneously*. Failure in one area would jeopardise the investments made in all other areas. If governments bet on wind and solar energy or other intermittent sources to power the national fleet of electric vehicles, they must also ensure simultaneous investments in smart grids and energy storage to ensure grid stability.

Unregulated markets are unable to trigger all the necessary investments in several interdependent technological improvements simultaneously. Hence industrial policy is needed to ensure coordination and incentivise actors. In Germany, the National Platform for Electromobility (Nationale Plattform Elektromobilität) was created to facilitate coordinated activities among carmakers, new suppliers, battery specialists, energy utilities, city governments and many others, and to identify technological gaps and research needs (see also Box 18).

In France, the government took an even more proactive approach. To overcome the 'hen and egg' problems related to consumer prices, slow uptake of BEV and lack of infrastructure, the government subsidises the purchase of BEV and nudges state enterprises and parastatals to purchase a large numbers of BEV, and at the same time commits large public investments into the charging infrastructure (Altenburg / Fischer / Bhasin 2012).

Policy responses to climate change as a market failure

Climate change – being both ubiquitous and exceedingly long-term – raises intricate environmental, economic and ethical issues. From a public goods perspective, these are most pronounced in the context of effective *mitigation action*, which requires coordination and negotiation at global level and opens massive space for free-riding behaviour on the part of individual nation states. In contrast, the benefits to be gained from *adaptation action* are both more localised and can be appropriated more directly (IPCC 2014).

Given the pervasiveness of market failures in dealing with environmental challenges, the question arises of how they can be effectively remedied. The orthodox economic response calls for the pricing (that is, internalisation) of externalities. In the case of climate change – and, for the sake of the argument, just concentrating on CO_2 emissions as the main driver – the solution would thus appear to lie in the appropriate pricing of carbon. This in turn can be achieved either by introducing a (Pigouvian)[4] carbon tax or by relying on a quota approach in terms of a cap-and-trade system (see Box 2). Alternatively, a direct regulation of permissible carbon emissions, as in the case of vehicle fleet management (see Box 14), would constitute an implicit pricing approach.

Box 2: Taxes and quotas as market-based green policy instruments

The function of a market is to balance supply and demand by determining an equilibrium market price and traded quantity of a certain good. In the case of externalities, however, this mechanism does not work: costs or benefits are not reflected in supply and demand, and the resulting price and quantity can be either too high or too low. For example, if producers can pollute the environment free of charge, their individual cost curves will not reflect true cost to society. They will produce too much at too low cost. Benefits may also be ignored, for example, if renewable energies contribute to cleaner air, but this positive effect is not reflected in higher prices. In these cases, the state can intervene and either correct the price or the traded quantity, that is, introduce a tax or a quota.

Quantities regulated through quotas may be minimum or maximum requirements, for example ceilings for renewable energy shares in the electricity mix, or caps on greenhouse gas emissions. Creating a market to trade certificates enhances efficiency, since firms can choose to buy certificates or reduce pollution themselves, whichever is cheaper. However, the possibility to earn money with the newly created certificates may also attract rent-seeking, as the limit values on which the price of certificates is based, are set by politics; politicians define, for example, how much a certain entity is expected to produce (for instance, what percentage of renewable energy each state in India should generate given its differential resource endowment) or which industries should be exempted from carbon certificate trading to safeguard their international competitiveness. Defining the conditions for certificate trading thus generates – in some cases enormous – rents, which in turn create strong incentives to lobby for exemptions or for changing limit values in the direction that would allow for the highest rents. Such instigation of rent-seeking behaviour may jeopardise the effectiveness and efficiency of this instrument.

The aim of environmental taxes is to add the social costs of pollution directly to the price. In the short term, taxes create incentives for behavioural change. In the longer term, and if reliable, they can also create incentives for environmental innovation. In theory, they can restrict the production of environmentally harmful goods and encourage sustainable substitutes up to the social optimum. In practice, however, it may prove difficult to determine the 'right' level of taxes for, say, the reduction of emissions by a given amount, since suppliers' cost curves and consumers' willingness to pay are not as a rule fully known to policy-makers. This shows the importance of the ability to gather reliable information on the market's reactions to price changes. For environmental taxes to be successful, governments also need the capacity to monitor and collect revenue and to enforce tax payment (ADB / IGES 2008). Environmental tax avoidance and evasion can reduce effectiveness significantly.

On the other hand, environmental taxes may be easier to impose than emission trading schemes. Most governments will already have a tax system that they can use for environmental purposes, while a trading scheme often needs to be set up from scratch. The regular discussion and revision of taxes in budget cycles enhances transparency and eases policy-learning. Firms may, however, lobby against taxes and for trading schemes – if they expect to succeed in their lobbying for the free allocation of certificates. Unlike taxes, which impose additional costs, freely allocated certificates bring additional gains: firms pass on to consumers the opportunity costs of using certificates for emissions rather than selling them on the market (Sijm / Neuhoff / Chen 2006). It is hardly surprising that the carbon tax recommended by the European Commission in the 1990s met with strong opposition from industry and that the proposal was withdrawn in 2001 (Spash 2010), to be followed by the introduction of the emissions trading scheme.

Source: Adapted from Pegels / Becker (2014)

4 Pigouvian taxes are taxes intended to correct market failures, obliging producers to pay for negative externalities. See also Box 2.

Without any doubt, the underpricing of environmental assets has contributed significantly to the past growth of the world economy. Concurrently, it has generated the unsustainable ecological footprint which we have locked ourselves into. Thus, there is a strong case for getting the prices right (prices of emitting carbon, of using material and energy resources, of generating pollution and waste) and have them reflect the prevailing scarcities. This would provide incentives to move from high-carbon to low-carbon technologies on the supply side and from unsustainable to sustainable consumption patterns on the demand side.

However, accurate pricing is not the end of the story and just serves as the point of departure for more ambitious green industrial policies. Apart from the ethical challenges of pricing biodiversity and individual species, going beyond pricing is necessary mainly for four different reasons:

- Prices can act as powerful incentives for technological and behavioural change yet the resulting adjustment period remains beyond control. At the same time, there are products and processes, which in view of their irreversible environmental consequences may call for immediate and decisive action or outright banning. Non-degradable plastics, persistent organic pollutants and ozone-depleting substances are cases in point – and have indeed triggered international collective action towards their gradual phase-out (see Box 13 on the Montreal Protocol).

- As the markets for environmental goods are socially constructed (see Box 2), they depend on political decisions just as much as 'command-and-control' instruments, such as legally established limit values for emissions. Furthermore, they have enormous implications for the creation and allocation of rents among firms, sectors and countries, and are therefore politically highly contested. While carbon taxes at the required scale are politically difficult to enforce, the existing cap-and-trade systems are also fraught with implementation problems: Firstly, lobbyists have so far achieved very generous exemptions which largely undermined the instruments' effectiveness. For example, as a result of generous quota allocations the carbon price of the European Emission Trading System (ETS) fell from a peak of EUR 30 in 2006 to a level below EUR 6 at the end of 2013. Secondly, a global agreement on emissions rights presupposes difficult international settlements, for instance, on how to value historical liabilities of early-industrialising nations or whether, in the case of global value chains, producing or consuming countries are accountable for emissions. For the foreseeable future, cap-and-trade systems are therefore likely to remain more a patchwork of national and regional initiatives than an instrument of global coverage (IEA 2010).

- The impact of setting appropriate prices may be restricted by other market imperfections (World Bank 2012), such as low price elasticities (limited consumer response to price signals, for example due to lack of technological alternatives or due to behavioural inertia), principal-agent problems (for instance, in the case of tenants paying energy bills thus reducing energy-saving incentives for owners) or lack of confidence in the long-term stability of politically set prices (as demonstrated above in the case of the European ETS).[5]

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5 Hepburn argues that currently the ETS carbon prices suffer from a credibility gap: *"The carbon prices that have so far emerged from two decades of policy attention are still not credible, and even if the spot*

- The introduction of environmentally sustainable technologies at the requisite scale and speed involves the breaking up of entrenched development paths. It calls for institutional and technological innovation and learning, ‘kicking old habits’ of behaviour as well as the creation of a new low-carbon compatible infrastructure (Hallegatte / Fay / Vogt-Schilb 2013). This massive challenge of societal adjustment coupled with the exceeding urgency of action thus requires more than simply getting the prices right. Regarding the latter point, that is, radical and systemic change requirements, the key task is to create incentives that push forward the development, testing, deployment and upscaling of sustainable technologies.[6] This in turn presupposes the combination of smartly designed subsidies (as in the case of feed-in tariffs for renewable sources of energy) with incentives to encourage and steer R&D efforts in the desired direction as well as investments into dedicated infrastructure and multi-stakeholder partnerships, such as in the form of regional innovation clusters.

All in all, ‘green’ investments are strongly guided by policy incentives that reflect political priorities rather than by prices resulting from unfettered supply and demand. In this context, market-based incentives have an important role in dealing with environmental externalities and public goods, but pricing is not sufficient and in many cases politically not even feasible. Hence policymakers need to combine different types of regulatory measures to achieve their objectives. However, this opens up a new set of problems, as policy measures may be incompatible, such that one measure undercuts the effectiveness of another. In this context, the alignment of different policy instruments assumes crucial importance. As illustrated in Box 3, for example, the parallel operation of an emission trading scheme and a feed-in-tariff can lead to perverse outcomes in terms of renewable energy subsidies decreasing demand for (and the price of) emission certificates, and thereby reducing incentives for emissions reduction in other parts of the economy. Harmonising different policy instruments thus assumes crucial importance.

Finally, proper carbon accounting is the basis for being able to address externalities and requires metrics for reflecting carbon content in the prices of goods and services. This is complicated by the fact that the fragmentation of international production leads to the phenomenon of ‘embedded carbon’. Seeking to measure the environmental impact (or more specifically the carbon footprint) of products, one has to dig deep into the geography of multi-polar production networks and reflect the conditions under which a myriad of components are being manufactured, packaged and shipped around the globe. Difficult as this may be, it is a necessary step towards accounting for carbon emissions on the final consumption side and not on the production side.[7]

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prices were ‘right’ (which they are not), additional intervention would be required ... to reward innovation” (Hepburn 2010, 127).

6 Nordhaus underlines that in fact two layers of externalities are involved: *“Investments in low-carbon technologies are depressed because the private returns on innovation are below the social returns, and private returns are further depressed because the market price of carbon is below its true social cost. The net effect is to doubly discourage profit-oriented R&D in low-carbon technologies”* (Nordhaus 2013, 286).

7 Not surprisingly, the decarbonisation of supply chains has become a widespread business objective (WEF 2009). In conjunction with other factors (such as rising transport and labour cost or new digital

Box 3: Challenges of policy harmonization: feed-in tariffs and emission trading systems

Around the globe, there is a strong yet uncoordinated growth of both emissions trading schemes (ETS) and renewable energy targets combined with feed-in tariffs (FiT). Both policy schemes are aimed at decarbonising the economic space they cover (be they regions or countries). The necessity to align these diverse policy measures needs to be stressed.

On the one hand, any FiT-induced lowering of CO_2 emissions reduces demand for emission certificates traded under an ETS, cuts their price, and thus discourages investments in further emission reductions (Böhringer / Rosendahl 2010; 2011). The parallel operation of FiT and ETS will thus crowd out the former's emission reduction benefits – at least for those emissions traded under the ETS. On the other hand, the lower price of certificates opens political space for tighter ETS caps without threatening the competitiveness of companies.

Specifically, the low price of carbon emission certificates traded under the European ETS currently does not counter the tendency of sinking prices at the European Energy Exchange. In Germany, this leads to counter-intuitive results: despite ETS and FiT, total CO_2 emissions have been stagnating in the past four years, and even rising in 2012 (Umweltbundesamt 2013). This development is at least partly due to oversupply caused by FiT-induced renewable electricity production: at times, electricity prices fall to the extent where only the cheapest sources are still competitive, that is, hard coal and, in particular, lignite in the case of Germany. Lignite, however, is exceedingly emission-intensive. As a result, paradoxically, the rapid deployment of renewables does not currently lead to decreasing total greenhouse gas emissions. The policy space that falling electricity prices could create to tighten ETS caps has not been used.

Although an ETS may crowd out the emission reductions of FiT systems, literature finds various arguments for complementing ETS with additional support for low carbon investments. Vogt-Schilb / Hallegatte (2014) argue that the long-term nature of developing low carbon technologies requires looking beyond the cheapest short-term mitigation options; Jenkins (2014) and Rozenberg / Vogt-Schilb / Hallegatte (2013b) emphasise the political economy aspects of ETS, such as difficulties to set sufficiently strict caps to spark investment in low carbon technologies; Lecuyer / Quirion (2013) stress that additional support instruments can create the required investment certainty for low carbon investments where fluctuating certificate prices fail; and Fischer / Preonas (2010) state that cost reductions through learning and spillover effects can be an argument for parallel instrument use.

Source: Adapted from Pegels / Lütkenhorst (forthcoming)

3.2 Addressing high uncertainty and long-time horizons

Industrial policy has always been faced with the perils of uncertainty, and with the need to venture into assessments and judgments that try to anticipate and shape desired future scenarios. Any industrial policy in action thus has to meet the challenge of limited information and risk-prone simulation of future scenarios; it is literally macro-management under uncertainty.

In the case of green industrial policy, the dependence on evidence derived from a variety of basic and applied natural sciences (geology, biology, physics, climate science, engineering, systems analysis, etc.) is fundamental. However, while these may generate reliable knowledge in isolation, the variance of projections grows in proportion with the level of multi-disciplinarity, the size of the system and the time horizon considered. The

technologies) it may conceivably lead to a future shortening of supply chains and a trend towards renewed 'insourcing' or 'reshoring' of production.

latest IPCC Report, for instance, presents us with evidence that global warming is unequivocal and manmade. However, its projections of mean temperature rises up to the year 2100 range from 1.0 to 3.7°C (compared to the reference period 1986–2005). Similarly the occurrence of heat waves with higher frequency and duration is considered very likely, yet exactly how and when they affect individual countries and what the economic effects would be, is highly uncertain.

Not to be misunderstood: we do not want to cast any doubt on the scientific evidence for, and the imperative and urgency to act against anthropogenic climate change. The most severe risk to be taken today is that of not acting at all. In addition to the general risk of global warming mentioned above, science warns us of several potential tipping points in global ecosystems beyond which environmental change will be abrupt, unmanageable and irreversible. However, policy makers are often in a quandary when having to take calculated risks that exhibit high and quantifiable immediate costs contrasting with uncertain future benefits. Behavioural sciences tell us that humans (and thus voters) tend to value immediate costs and benefits irrationally high, thereby damaging future generations, or even damaging themselves in the long run (Phelps / Pollack 1968; O'Donoghue / Rabin 2000). Furthermore, the uncertainties provide entry points for political capture: while the fact of discernible and significant man-made climate change is proven and potentially disastrous consequences are written on the wall, the lack of precision in long-term forecasts (coupled with short-term political mandates) leaves room for escapist positions held by powerful groups of vested interests. This is exacerbated by the often controversial nature of research findings, in particular when it comes to translating global climate models into regional and national scenarios, which involve higher levels of uncertainty. Against this backdrop, it is easy to find hired guns that provide elaborate justifications for any conceivable policy position. Indeed, evidence-based policy-making (necessary as it is) is often constrained by what has been termed *'policy-based evidence-making'* (Geden / Fischer 2014).

Moreover, uncertainty stemming from the scientific modelling of climate change is compounded by further spheres of uncertainty, within which policymakers have to act:

- The *dynamics of complex ecosystems* are unpredictable and subject to erratic tipping points. There is already mounting evidence of catastrophic climate change, irreversible loss of biodiversity and risks of collapsing water systems due to increasingly anoxic conditions. If indeed *"our emotional apparatus is designed for linear causality"* (Taleb 2008, 88) and most of our economic models are based on the notion of marginal variation rather than abrupt, discrete change, then we are ill-equipped to deal with such non-linear events.

- The *technical feasibility and commercial applicability of new transformative technologies* (at the required scale and at affordable cost levels) is inherently doubtful. This applies equally to innovative energy storage technologies, different approaches to electric mobility or the future potential of carbon capture and storage (CCS) technologies (see Box 4). Furthermore, many technological solutions for one problem may create new problems in other domains – the use of biofuels as a low-carbon source of energy may threaten food security; nuclear energy as a low-carbon technology comes at high risks of radioactive emissions and security issues; the 'fracking' of shale gas may pollute groundwater tables, etc. Societies tend to assess such risks differently, as demonstrated by the diverging national responses to biofuels, nuclear energy and fracking, which adds another layer of uncertainty: Even when technological solutions are feasible and commercially viable, they may not be socially acceptable.

- *Global policy approaches* are both necessary and notoriously slow to emerge. International climate negotiations within the framework of UNFCCC have delivered a series of disappointing outcomes. Whether or not this is bound to change at the next milestone (COP 21 end of 2015 in Paris) is anyone's guess. At the same time, supranational carbon markets remain in their infancy and – assuming they do not fail altogether – are likely to take many years to become politically and operationally stable. Investors and policymakers alike can therefore hardly anticipate which internationally agreed targets or which carbon offsetting costs they have to factor into their strategies.

- The *impact of innovative policy instruments* cannot be predicted with any reasonable level of precision. More often than not, unexpected and unintended consequences occur. For instance, a few years ago hardly any analyst predicted the breakdown of the European ETS market; Germany's feed-in tariff, in contrast, drastically overachieved its targets, such that the economic costs of the price differential required an overhaul of the scheme.

Box 4: Carbon capture and storage (CCS) – panacea or red herring?

CCS is a bridging technology that could allow the continued reliance on fossil fuels, in particular coal, in generating electricity and powering a wide range of industrial processes. In essence, the CO_2 thus generated would be captured, compressed, mostly transported over long distances and ultimately buried in underground geological formations. Most current emission reduction scenarios assume the commercial application of CCS at scale – contributing as much as one sixth of global CO_2 emissions reductions in IEA's 2°C scenario for 2050 (IEA 2013a). Hence, the integrity and validity of long-term climate change projections stands and falls with the technological and economic prospects of CCS.

At the same time, the viability of CCS at industrial scale has never been demonstrated while additional concerns have been raised regarding the risks of long-term CO_2 leakage. Presently, big industrial players are abandoning CCS demonstration projects: more than 30 large-scale projects have been cancelled or put on hold, mostly in the United States, the European Union, Canada and Norway (MIT 2014). This is due to a variety of factors, including unexpected technological challenges, massive cost increases (60% above conventional coal power plants) and lower fuel efficiency (30% below conventional coal power plants).

As a result, the jury on the potential impact of CCS is still out. Bold assumptions persist yet may be totally unfounded. Hence, there seems to be a compelling case for a global effort to arrive at a shared assessment of the feasibility and impact of CCS. While the future of 'clean coal' rests almost entirely on massive CCS application, the costs of demonstration projects are huge and need to be widely shared. However, the requisite collective action is not in sight, *inter alia* due to lacking co-benefits (outside the realm of climate negotiations). Priority should be given to pooled, public and private funding for R&D and testing of CCS, including the required transport infrastructure. Only if and when the technology's viability is established, would it make sense to push for its application, *inter alia* through the requisite regulatory provisions. As long as the feasibility and social acceptability of CCS are not proven, governments and societies may have to prepare for more ambitious decarbonisation scenarios that would allow the world to stay below 2^{o} degrees global warming even *without* CCS.

In a nutshell: nothing is certain, yet everything is at stake. However, there is a conceivable risk of catastrophic events unfolding – hence erring on the side of caution, acting today, defining appropriate responses, taking calculated risks and testing new policy instruments is exactly what a proactive green industrial policy is responsible for (see Box 5). At the same time, providing space and mechanisms for systematic policy learning and introducing safeguards that minimise the risks of failure or unanticipated effects of new policy instruments is crucial (see Section 5).

Box 5: The German energy transition: policies for the long haul
One of the most ambitious green industrial policy projects is currently unfolding in Germany in terms of a fundamental transformation of the country's energy system. Political objectives put a premium on climate change mitigation, a rapid nuclear phase-out and the massive expansion of renewable energy (accounting for 24% of electricity generation in 2013). The strategy has received strong social backing to date. Innovative and competitive industries are exporting German energy technologies to expanding global markets, providing a prime example of the new industrial revolution towards climate-friendly economic development. While this fundamental energy transition (*Energiewende*) is more than a 'gamble' (Buchan 2012), it is not without risk. Germany's pioneering role in transforming an established energy system in an industrial society is the subject of immense global interest. Depending on where observers stand in the spectrum of climate policy, they want the energy transition to either become a resounding success or to fail. The limitations of a 'go-it-alone' approach by Germany are also becoming increasingly apparent. The close interlinkage with the European ETS calls for greater coherence and alignment between regional and national policies. Also, key challenges have remained unresolved so far. These include grid expansion and integration, the development of large-scale energy storage capacities as well as the excessive incentives for solar power, which failed to anticipate the precipitation in the price of solar photovoltaics modules and the massive competition from Chinese manufacturers. However, an industrial and energy policy geared towards sustainability and societal transformation must accept a certain degree of calculated risk and even setback while not losing sight of its long-term objectives. The costs of the energy transition (for example, in the form of electricity price hikes) can be immediately accounted for. The same is not true for the long-term benefits of being in the vanguard of establishing a sustainable energy system and building up new sources of technological leadership, competitiveness and employment.

3.3 Creating new pathways

The sustainability transformation – at global and national levels – sets an agenda of non-incremental radical change, of disrupting old pathways and creating new ones. While Sub-section 3.4 will deal with the former aspect, this section addresses the thorny task of identifying, charting and promoting new pathways. It starts with the reality of path dependency and lock-in effects, highlighting the role of strategic niche management in breaking up entrenched patterns. This is followed by a link to the long-standing industrial policy debate on targeting new sectors or technologies as a way to create innovative pathways. A necessary focus on transformative technologies is emphasised, including the need to address the role of bridging technologies. Finally, we point to the global dimension of policy and market interdependence.

The role of path dependency and lock-in effects

The technological and institutional systems that have shaped today's carbon economy exhibit high levels of inertia. Terms like 'technological paradigms', 'trajectories' or 'pathways' are indicative of the persistence of systems, which – once created and set in motion – lead to path dependency and lock-in effects. These tend to be particularly strong and difficult to surmount in the case of 'carbon lock-in'.[8] Unruh (2000) has demonstrated how carbon lock-in is generated at the micro level of firms, permeates entire techno-industrial systems at meso level (involving dedicated infrastructure, standards and networks to become an entrenched 'dominant design'), is exacerbated by co-evolutionary forces of building up related social capital (professional networks, associations) and is ultimately reinforced by government policies.

In this context, the role of policy is ambivalent. On the one hand, government intervention has the potential to crack a path-dependent, locked-in technological system that has developed from market forces. On the other hand, there is a well-documented tendency for government agencies and policy institutions to become deeply entrenched themselves and work towards their own perpetuation. This makes radical policy change (as opposed to incremental change) more of an exception than the rule and renders it likely that external shocks are needed to trigger policy change (Unruh 2002; a more nuanced neo-institutionalist treatment is provided by March / Olsen 2005).

In the absence of external shocks shaking up an existing techno-industrial system, what can be done by policy? One option is to rely on strategic niche management (Kemp / Schot / Hoogma 1998; Unruh / Carrillo-Hermosilla 2006). This involves policy-induced experimentation with technological alternatives for existing carbon-based trajectories. While such an approach by its very nature is gradualist and would use 'protected testing spaces' for hopeful yet still uncompetitive technologies, the selection of such spaces poses its own challenges. They need to be small enough to remain below the radar screen of powerful incumbents with competing commercial interests that might otherwise seek to sabotage success. At the same time, they must be sufficiently complex to allow for an effective simulation of 'lock-out' scenarios. For instance, the current proliferation of sustainable urbanisation models and the formation of networks of 'green cities' could be a promising platform for scaling up what has shown to work. Moreover, such niches or testing spaces need to overcome the technology push bias prevailing in most societies, that is, they must allow for experimenting also with social innovation (e.g. car-sharing models), new consumption practices and new types of dedicated infrastructure (Schot / Geels 2008). Box 6 demonstrates how potentially path-disrupting new technologies can be tested and nurtured in protected policy spaces, and what would be needed to scale them up such that they can seriously challenge the old dominant technological paradigm.

In a stylised perspective, what is needed is an early lock-in (sic!) of forward-looking sustainability-oriented policies. Karp / Stevenson (2012, 26) have pointed out that *"the endogeneity of future policy and the inability of current policymakers to make binding commitments regarding future policy, create a rationale for green investment policy"*. In other words, while the commercial viability of a new green technology (for example, large-scale

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8 The IEA's sobering assessment illustrates the magnitude of carbon lock-in: *"Four-fifths of the total energy-related CO_2 permissible by 2035 in the 450 Scenario are already 'locked-in' by our existing capital stock (power plants, buildings, factories, etc.). If stringent new action is not forthcoming by 2017, the energy-related infrastructure then in place will generate all the CO_2 emissions allowed in the 450 Scenario up to 2035, leaving no room for additional power plants, factories and other infrastructure unless they are zero-carbon, which would be extremely costly"* (IEA 2011, 40).

Box 6: Strategic niche management – trying to overcome path dependency

Across the world, governments and the private sector are experimenting with radically new technologies. Governments can create policy spaces where new, immature technologies are protected from the overwhelming competition of incumbent technologies. Technological lock-in implies that existing technologies asphyxiate the search for alternatives which, at their early stage, are technically not mature, too costly without economies of scale, not fitting existing laws and regulations or consumer preferences, or which depend on complementary investments. Protecting such experiments may give them the opportunity to learn and improve the respective technology, but also to show what is feasible and convince the public, to attract investors and build networks of interested stakeholders who may lobby for policies to expand the experiments beyond their initial niche status (Kemp / Schot / Hoogma 1998).

In many countries, the feed-in tariff for renewable energy has created such a niche. It allowed the testing and improvement of solar and wind energy technologies, the building up of manufacturing capabilities which then allowed the technologies to close the performance gap *vis-à-vis* fossil fuel technologies, and – not least – the legitimisation of the new technologies and the establishment of a political support base to counter the lobbying power of the incumbent energy utilities.

Similarly, many countries have recently established fleet trials with electric vehicles and new mobility concepts. Here, automotive companies, energy utilities, other transport companies and city governments join forces to test the performance of new vehicles or mobility concepts, such as car sharing, or concepts that integrate public long-distance travel with individual low carbon transport for the last mile. Such experiments allow us to test and improve technological performance, to learn about consumer behaviour and to explore unconventional new alliances. Moreover, it allows consumers and policymakers to become familiar with alternative concepts and thereby enhances political legitimation and public support.

offshore wind turbines) depends on policy decisions that will be taken far into the future, such decisions cannot be guaranteed by current governments. What a government can do however, is to create markets for green investments (for instance, through feed-in tariffs for renewable energy), which trigger learning effects and economies of scale – and in turn increase the pressure on future governments to continue on the same path, in other words, to enhance the ‘endogeneity’ of future policies.

Obviously, there is a trade-off involved here. On the one hand, it can be argued that a whole range of technologies should be allowed to develop and prove their viability so that a new lock-in does not occur too early and a diversity of solutions is being nurtured (Marechal / Lazaric 2010). On the other hand, commercial profitability requires upscaling in large markets, which are significantly determined by policy-induced economic incentives. How long should policymakers watch and encourage experimentation and when should particular technologies be selected and further promoted? Fostering innovative technological alternatives may be a costly process yet ‘big push’ subsidies may also result in bringing down costs fast. We are back to the essential point of green industrial policy having to take well-calculated risks. This has significant implications for organising a transparent and learning-oriented policy process (see Section 5 below).

Behavioural patterns and consumer preferences

It is stating the obvious that any industrial policy affects both producers and consumers of goods and services. Even more mundane interventions like promoting the upgrading of a country’s clothing industry or incentivising the development of certain information technology products presuppose that the producer capabilities so created will be matched by corresponding consumer preferences and effective demand. Of course this leads straight into the tricky terrain of creating new needs: Who was really missing a tablet computer before it was invented? Who needs ever-shorter clothing fashion cycles? And what is the genuine need served by driving an SUV (sport utility vehicle) in an urban setting? The list of such questions is both endless and futile. We may easily agree that there are legitimate and false needs, basic and luxury needs, natural and artificial needs – yet where to draw the line is not a question ever likely to be solved by economic research and certainly not a question addressed in this paper.

However, compared to industrial policies targeting specific sub-sectors of the economy, the ambition of green industrial policy is far higher. It amounts to nothing less than transforming an economy in its entirety. Based on the recognition that our current ecological footprint by far exceeds the carrying capacity of the planet, it becomes imperative to bring about radical change and move to a new paradigm. In the first place, this involves decoupling future growth from material resource use (‘dematerialisation’), for instance, through circular economy and cradle-to-cradle business models (see Box 7). More fundamentally, in the case of affluent economies, it calls for the questioning and rethinking of a development model that defines human well-being entirely within a growth logic (Jackson 2009).

Box 7: Decoupling growth from material resources: the circular economy

The circular economy is an industrial economy approach to dematerialisation, which involves a careful management of material flows along the lines of ecosystems. This approach builds on various concepts/models to integrate sustainability principles in industrial design (e. g. closed loops processes in which waste serves as an input), such as ‘regenerative design’, ‘performance economy’, ‘cradle-to-cradle’, ‘industrial ecology’, ‘biomimicry’, and ‘blue economy’.

In the circular economy, material flows are of two types as described in the cradle-to-cradle concept (Braungart / McDonnough 2009): biological nutrients, designed to re-enter the biosphere safely and build natural capital, and technical nutrients, which are designed to circulate at high quality without entering the biosphere (i.e. being used in continuous cycles as the same product, instead of being downcycled into lesser products and becoming waste).

The circular economy approach to industrial design draws a sharp distinction between the consumption and use of materials: circular economy advocates the need for a ‘functional service’ model in which manufacturers or retailers increasingly retain the ownership of their products and, where possible, act as service providers – selling the use of products, not their one-way consumption. This shift has direct implications for the development of efficient and effective take-back systems and the proliferation of product- and business-model design practices that generate more durable products, facilitate disassembly and refurbishment and, where appropriate, consider product/service shifts (Ellen MacArthur Foundation 2014).

A recent report launched at the World Economic Forum in Davos in 2014 (WEF 2014) highlights a plan of action for scaling-up this concept. The key recommendations are: to set up global reverse supply cycles for products and components, to reorganise and streamline pure materials flows (e.g. for major global raw materials, such as polymers, steel and glass), and to innovate business models on the demand side. Based on recent estimates, a McKinsey analysis shows that, if a subset of the EU manufacturing sector adopted circular economy business models, it could realise net material cost savings worth up to USD 630 billion per year by 2025 (Ellen MacArthur Foundation 2012).

This in turn presupposes a shift to sustainable lifestyles and consumption patterns, which challenge not only the way we produce but also the way we consume, work, travel, communicate and trade. Intriguingly, enlightened business circles themselves have come to realise that, without this shift, the very foundation of future growth is at stake: *“Action to* *decouple business and economic growth from resource intensity and environmental impact has never been more critical to the long-term success of business"* (WEF 2012a, 5).

The twin challenge of green industrial policy is thus to promote the development and deployment of a new generation of resource-efficient and climate-friendly technologies while at the same time stimulating their uptake by business and consumers alike. For the latter to happen, entrenched habits and forms of behaviour need to be overcome. However, as various strands of evolutionary economics and behavioural sciences have clearly demonstrated, a variety of biases and misperceptions result in bounded rationality governing the behaviour of economic agents both as producers and consumers. The energy-efficiency paradox (Jaffe / Stavins 1994), namely investments towards more efficient use of energy in production processes not being undertaken despite their high financial returns, is just one striking example.[9]

More generally, there is evidence of widespread inertia in how individuals exercise economic choices. Such inertia is not (or only partially) the result of strictly economic market failures. From a behavioural perspective, it becomes essential to consider the multitude of factors that determine why people act the way they do and to identify the primary drivers. In this, shared social norms and practices play a crucial role and can easily create path dependency not only in technological terms but also in consumption behaviour. Therefore, just like creating lead markets for new technologies, it can be highly effective to identify and showcase intrinsically motivated 'lead users', who pioneer new sustainable forms of consumption (Marechal / Lazaric 2010) and can serve as avant-garde role models. To illustrate these points, Box 8 summarises key findings of behavioural sciences.

Box 8: Evidence from behavioural sciences

Contrary to (neo)classical economics, behavioural sciences question the assumption that rationality is the sole basis of human decision-making. Behavioural sciences see the well-informed maximisation of utility, the determinant of decisions in rational choice theory (Becker 1976; Olson 1965), as only one subset of drivers of human behaviour, the others being social, ethical and psychological drivers. Simon (1957) also questions the unlimited ability of humans to obtain and process information in the pursuit of their goals ('bounded rationality').

Policy can use these insights to steer individual decisions towards a desired outcome, for example by using nudges (World Bank 2012). Thaler and Sunstein define a nudge as 'any aspect of the choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid' (Thaler / Sunstein 2008, 6). Nudges, though an important policy component for green transformation, have yet to be explored in any depth. As their aim is to change human behaviour rather than influence the rate or direction of technological progress, they are particularly suitable in areas which are difficult to tackle with technology alone, such as reduced and sustainable consumption and recycling. As examples for environmental nudges, Thaler and Sunstein mention the 'Ambient Orb' device, which reflects energy consumption by changing colour, and the Toxic Release Inventory, which requires firms and individuals to disclose information on hazardous chemicals which they store or release into the environment. The social pressure of the press and public opinion, focused on the worst polluters, gives them a strong social nudge to mitigate pollution (World Bank 2012).

9 However, the lack of uptake of new green technologies can also be the result of *rational* individual behaviour, for example, reflecting their higher costs or the benefits (including subsidies) derived from old polluting technologies. Hence, influencing uptake requires a mix of regulatory measures, traditional incentives, policies to enhance the transparency of markets (such as through standards and labels) and attempts to overcome bounded rationality.

Box 8 (cont.): **Evidence from behavioural sciences**
Another way to change behaviour is to change the default options. Empirical studies show that people are more inclined to accept a pre-set default option than to opt out (see, for example, Brown et al. 2012; Center for Research on Environmental Decisions 2009; Pichert / Katsikopoulos 2008). Flight booking websites, for instance, can make the offsetting emissions option the default, forcing customers to do something if they want to opt out. In the long run, individual changes in behavioural patterns can be made permanent by learning. Weber and Johnson (2012, 10 ff.) state that individuals learn from the experience of others or from their own experience. Learning from the experience of others may occur through observation and imitation. This stresses the importance of feedback from 'green' peer groups and trendsetters in nudging others towards environmentally conscious behaviour. The prompter the feedback, the better, since individual learning has a recency bias: recent events carry more weight in decision-making processes than events in the more distant past (Hertwig et al. 2004). This may raise difficulties for avoiding such long-term environmental threats as climate change, since the effects of polluting actions will be felt only in the future. Furthermore, recency bias leads to an underestimation of the risk of rare extreme events. However, if any such events occur, they can open a window of opportunity for industrial policy measures that capitalise on impressions still alive in people's memories
Source: Adapted from Pegels / Becker (2014)

In order to allow well-informed choices and influence consumer behaviour, markets need to be transparent. Often, consumers do not opt for more sustainable products and services simply out of lack of information. This may for instance be related to the carbon footprint (see also Sub-section 3.1) or to the energy cost-saving potential of different products. A range of options can enhance transparency, including public or private standards, which in turn may be either voluntary or mandatory. Box 9 presents evidence from India on a successful approach to sequencing the adoption of energy-efficiency standards.

Box 9: Using voluntary and mandatory standards to promote green consumption: the case of energy-efficient household appliances in India
With increasing urbanisation and growth of middle class consumers, demand for electrical household appliances has rapidly increased in India and accounts for a considerable share of the country's energy consumption. Despite the entry of large multinationals, such as Hitachi, LG, Philips and Whirlpool, firms almost exclusively used to serve the market for simple technologies at low sales prices – at the expense of energy efficiency. In 2006, the Bureau of Energy Efficiency (BEE) initiated its Standards and Labelling Programme to provide consumers with information about energy consumption and the related cost-saving potential of electric appliances. It encouraged firms to adopt voluntary energy efficiency standards and introduce a one-to-five stars labelling scheme to categorise products with different levels of energy efficiency. In addition, manufacturers were given incentives to invest in product improvements, and the labelling scheme was aggressively promoted in the media. All relevant stakeholders, from manufacturers to electric utilities, standards bodies and government agencies were extensively consulted during the design phase of the programme. About three years later, the voluntary labels had already gained credibility, and consumers had increased the purchase of labelled products. For refrigerators and air-conditioners, sales of labelled products surpassed 50% market share by then. At this stage, when consumers widely knew about, and relied on, the star labels to make informed purchase decisions, performance standards were made mandatory for a range of household appliances. In the meantime, the BEE had encouraged manufacturers to adopt approved testing systems and self-certify their products, and it had built up a testing infrastructure to check-test samples of household appliances drawn from the market in order to verify the information provided by the manufacturers.

Box 9 (cont.):	**Using voluntary and mandatory standards to promote green consumption: The case of energy-efficient household appliances in India**
The Standards and Labelling Programme has thus created a quality label that created market transparency while helping firms to widen their product range and launch better products. At the same time, it made a substantial contribution to energy savings in India. The BEE estimated energy savings of 7 GW during India's 11th Five-year Plan period (2007–2012). Starting with *voluntary* standards and building on partnerships with powerful firms was an appropriate strategy to prepare the market and phase-in energy efficient alternatives; later shifting to *mandatory* standards helped to phase-out the undesirable inefficient technologies. Firms and consumers were given time to react, and the voluntary investments of those firms that had joined the phase of market preparation provided them with an early mover advantage when standards became mandatory. BEE adopted similar strategies to phase in energy efficiency standards in other fields, such as residential and commercial buildings, or LED lamps. Strategies were designed differently depending on the characteristics of each area of energy use, but success always depended on smart sequencing of voluntary and mandatory standards as well as extensive stakeholder involvement.	
Source: Chaudhary / Sagar / Mathur (2012)	

Nurturing new technologies – not picking winners

The issue of long-term political visions, goals and targets that challenge the status quo and trigger transformative change is of course not new to the discourse on industrial policy. Indeed, it epitomises the current debate as illustrated by the recent controversy between Lin and Chang (2009) on whether to assert or defy a country's existing comparative advantage. The main case argued about in their debate (the Korean push into steelmaking as a strategy to create a non-existent advantage) is certainly an example of disruptive change. However, it is nowhere near the daunting task of green industrial policy to manage the fundamental transition away from a high-carbon economy.

Hence, the somewhat stale debate around picking winners is wide off the mark and does not do justice to the scale of the challenge connected to the green transformation. The whole notion of a centralised, top-down selection ('picking') of new technologies is misleading. Any enlightened industrial policy (green or otherwise) is genuinely about opening up discovery spaces, facilitating collective priority-setting and focusing collective action on overcoming coordination failures, rather than arbitrary selection by bureaucrats, as it is sometimes depicted by critics of industrial policy (e.g. Pack / Saggi 2006). The result (not the starting point) of such an organised process will be the selection and nurturing of new industrial technologies and sectors – by the way, a point on which Lin and Chang (2009) explicitly agree.

Indeed, we would argue that in conceptualising green industrial policy, a focus on transformative technologies should replace the traditional emphasis on industrial sectors. The long-standing debate around policy targeting has so far been dominated by a distinct sectoral bias. The questions asked were mostly whether to promote textiles or clothing industries, whether to venture into electronics or automotive industries, whether to concentrate on specific products, components or tasks within global value chains and how best to create the capabilities (such as skills, knowledge, dedicated infrastructure) to upgrade existing capacities and attract new investment into the chosen target sector.

This conventional industrial policy focus needs to be revisited. Within a low-carbon development scenario, a strong case can be made for the targeting of resource-efficient technologies across a broad spectrum of sectors (see Box 10). The imperative of prudent and efficient resource use ranges from increasingly scarce raw materials to water and energy – and evidence abounds on the business case for investing into efficiency-enhancing technologies, which reduce the pressure on resources and ecosystems, and impact positively on the financial bottom line.

Box 10: Promoting 'efficiency technologies' in Germany
Priorities for research funding in Germany are gradually changing. There is a discernible trend towards Federal Government funding for cross-cutting, efficiency-enhancing technologies. Dedicated programmes finance research initiatives focusing on energy-efficiency and material-efficiency in manufacturing technology, process engineering, machinery and components as well as industrial product properties. One specific outcome of such research is a Resource Efficiency Atlas offering a compendium of technologies suitable for application in different sectors (Wuppertal Institute for Climate, Environment and Energy 2011). Similarly, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) has launched broad initiatives around the notion of so-called research beacons, which are meant to guide and support research into future-oriented green technologies, such as urban mining (including commercial use of construction and demolition waste) and electric mobility. Explicitly, these initiatives go beyond narrow technological objectives and are intended to *"help to mobilise social forces, create social acceptance, and foster self-understanding in a society"* (BMUB 2008, 34). In other words: The identified research beacons set ambitious normative targets, yet leave the more specific technology choice as open as possible.

There is widespread agreement that a deliberate technology push is necessary to bring a whole generation of new low-carbon technologies to market and to scale and that, to this end, radical innovation as opposed to incremental innovation is required. Historical examples of mission-type technology programmes, such as the Manhattan (atomic bomb) and Apollo ('man on the moon') projects, have been invoked. Indeed, new 'technology missions' may also be required today as a way of orchestrating a big technology push and ensuring the simultaneous development of several interdependent parts of a major technological solution, e.g. to develop innovative energy storage technologies or scalable CCS technologies. However, the historical analogy to the Manhattan and Apollo missions is partly misleading (see Mowery / Nelson / Martin 2010 and Yang / Oppenheimer 2007 for a comparison with today's climate change challenge). Unlike in these historical cases, the challenge of a deep decarbonisation of today's economic systems is confronted with:

- Sustained efforts to replace existing and promote new technologies that are likely to extend over several decades of transformation;
- the need not only to develop new technologies but also to promote their diffusion across virtually all economic activities and beyond national borders to achieve global scale; and
- the acceptance of new technologies by consumers with concomitant changes in long-standing patterns of behaviour.

Hence, a different type of a sustained technology policy is called for. Based on clear commitments towards long-term goals, thematic technology corridors can be defined in which guided discovery processes are organised. This would translate into state guidance and direction combined with private sector experimentation. At the same time, action among a variety of stakeholders would need to be orchestrated in terms of organising focused innovation clusters, setting priorities, allocating resources, adjusting incentive systems and complementing a technology push with a demand pull strategy. The implications for designing systems of governance that can actually deliver the expected results are immense given that incipient technologies require commitment and support well before approaching commercial maturity (Pegels 2014b).

The need for bridging technologies

In view of the long transition periods involved, the challenge is exacerbated by the need to rely on bridging technologies – such as gas and possibly clean coal in the energy mix (see Boxes 4 and 11) or hybrid car solutions in the transport sector –before the low-carbon technologies of the future are known, tested and economically viable.

Box 11: Energy access or sustainable energy – getting less dirty before getting clean?

'Sustainable Energy for All' is the well-intentioned slogan of a high-profile initiative by the UN Secretary-General. However, in many countries the much-needed access to energy (overcoming 'energy poverty') would seem to be in conflict with the goal of relying exclusively on sustainable, that is, non-carbon energy sources. While an increasing number of developing and emerging economies strive for a sustainable development pattern, there are thorny issues along the road. If for a transition period coal-fired power plants have to be part of the energy mix, what should be the response of government policies? Can they afford to be fundamentalist or is there a case for pragmatism?

In most countries, there is an existing stock of conventional coal-fired power plants. These tend to be inefficient, highly hazardous for human health, and damaging for the global climate. Investments into their improved maintenance, rehabilitation and modernisation can yield significant benefits and would 'buy time' for long-term investments into renewable sources of energy. Where should the red line be drawn? Are such incremental carbon investments defendable while there should be a hands-off approach towards investing into full-blown new coal power plants? And if so, what criteria should guide second-best support programmes? One approach could be to adhere to the minimum requirements (in terms of CO_2 emissions) set by various private funding institutions.

In this context, development cooperation agencies are also facing a dilemma. In order to be a credible and accepted partner for national governments, development agencies need to respond to the prevailing national discourse and appreciate the multiplicity of objectives: from bringing energy to marginalised population groups (access) to supplying growing businesses with reliable power (competitiveness) and ultimately transiting towards a green transformation (sustainability). Even from a purely environmentalist perspective, using financial resources for rehabilitating an old coal-fired power plant may reduce more emissions than using them for a wind park and leaving the old power plant unchanged. Tough choices are frequently called for and an appropriate sequencing of decisions is required. By being fundamentalist in terms of a 'renewables only' approach, development agencies risk moving themselves out of the policy dialogue and thus out of the solutions space.

The fierce controversy around the Medupi Coal Power Plant in South Africa – being established with support from both the African Development Bank and the World Bank – exemplifies the above considerations. (For a more detailed assessment, see Hermwille 2014.)

Moreover, care must be taken that the technological options space is not narrowed down too early. For instance, this applies to renewable energy promotion policies, which are well advised to encourage different technologies (onshore and offshore wind, solar photovoltaics, concentrated solar power, biomass etc.) rather than targeting a single technology purely on short-term cost-efficiency grounds.

Going global: Interconnected lead and lag markets

Creating new pathways is necessary to protect global environmental goods, but it is also costly. Convincing national governments to shoulder the high upfront costs and risks as part of their global responsibility is unlikely to be politically feasible. However, even from a purely national perspective it may be wise to engage in green technologies early on if this translates into early mover advantages in the global division of labour. For instance, Denmark's early investment in wind energy is a clear example of a forward-looking strategy that has paid off in terms of national competitiveness and jobs (Lema et al. 2014). Also, the German energy transition is driven by both environmental and economic objectives with explicit reference to strengthening Germany's global market position for climate-friendly technologies, boosting the innovative capabilities of industry and creating employment opportunities from renewable energies (Lütkenhorst / Pegels 2014, 8).

The fundamental question is whether it is preferable from an economic perspective to create a lead market or to rely on a latecomer strategy. In other words: Does is pay to be the early bird catching the worm or should one aim at being the second mouse getting the cheese?

Mostly, lead markets are defined in technological terms, that is, as markets that pioneer certain types of innovation, which can be either related to industrial processes or to a particular product design feature. In this understanding, lead markets are frequently developing in high-income settings based on a combination of companies able to scale up the diffusion of a technological innovation and discerning consumers ready to respond (Beise 2001).

More recently, the concept of *technology-induced* lead markets has been complemented by research pointing to the possibility and reality of *policy-induced* lead markets. In this context, the importance of co-evolutionary dynamics between policy, technology and market development is being emphasised. In the field of environmental technologies, ambitious government regulations and standards are often the main drivers of innovation. Contrary to the traditional view emphasising the negative, cost-increasing effects of demanding standards, they can translate into early mover advantages when other countries adopt similar standards only at a later stage (Porter / van der Linde 1995; see also the assessment of the Porter hypothesis by Ambec et al. 2010).

One of the prime examples is the huge lead market created in Germany for solar photovoltaic technologies as a direct result of politically guaranteed feed-in tariffs. Meanwhile however, within a short time span of less than a decade, large segments of this market that was initially dominated by German firms have been taken over by Chinese manufacturers. Thus, *"China, a lag market in terms of demand, has played a key role in fuelling the expansion of supply to the emerging lead market"* (Quitzow 2013, 56). These dynamics clearly demonstrate (a) the rising intensity and speed of the interconnectedness of green technology markets and (b) the challenge for a green industrial policy to safeguard the long-term domestic appropriation of critically important co-benefits, such as growing employment and enhanced competitiveness. Policymakers thus need to consider not just whether a specific environmental regulation stimulates new capabilities that can compensate for the additional costs imposed on national producers. If indeed they want to reap the co-benefits of environmental innovation, action needs to be taken to sustain the early mover advantages in the long run.

3.4 Disrupting old pathways

This sub-section emphasises that not only building up a new green economic development pillar but also dismantling the existing brown pillar of polluting industries will require creative policy approaches. We take up the topical debate around stranded carbon-based assets and more specifically, the existence of a 'carbon bubble'. This refers to carbon resources that – from a climate-change perspective – will have to remain unburned, in other words: commercially unexploited. Furthermore, we provide practical examples of gradual pathway disruption in terms of phasing out ozone-depleting substances and tightening vehicle emission standards.

So far, the debate and literature on managing green policy rents (see Section 4 below) has centred on 'investment-encouraging' incentives, namely those that seek to stimulate new economic activities that can underpin the required sustainability transformation and gradually lock-in a new green trajectory, as discussed in Sub-section 3.3 above. More specifically, this applies to, for example, promoting energy efficiency in buildings; subsidising the deployment and use of renewable energy; or initiating new systems of electric mobility.

Stranded assets …

However, the flip side of 'investment-discouraging' incentives needs to be factored in as well. The issue at hand is how to deal with those fossil fuel investment assets that are on the losing side of long-term structural change and face the prospect of a massive devaluation. While a (sufficiently high) carbon tax would induce the early 'mothballing' of such 'brown' productive capacities, the resulting employment losses and intense pressure for structural change are politically unacceptable in most societies. Hence the preference for policy instruments that incentivise new green investments while allowing the 'brown' capital stock to complete its economic life span – a strategy that prolongs adjustment periods at the expense of long-term welfare losses (Rozenberg / Vogt-Schilb / Hallegatte 2013a).

In the green industrial policy debate, attention to such sunset industries has generally been lacking. More recently however, this aspect has gained some prominence under the label of stranded assets. It is relevant for two different reasons: from a political economy perspective, the powerful vested interests and lobbying groups connected to those stranded assets have the potential to derail – or at least significantly delay – the green transformation. In addition, from a more narrow financial perspective, the massive amounts of capital involved can have severe repercussions in terms of creating market instability (see the examples provided in Box 12).

…and unburnable carbon

In the relevant literature, the notion of unburnable carbon is gradually moving to centre-stage. Starting from the concept of a global carbon budget (Meinshausen et al. 2009), that is, the amount of carbon still available for release into the atmosphere under a 2°C scenario, the aim is to quantify the amount of carbon resources that, though existing, cannot be burnt anymore. Based on quantitative modelling exercises, it is estimated that in a realistic scenario without widespread use of CCS technologies, approximately 45% of all 'proved and probable' oil resources (equalling an amount of 600 Gb) must remain unexploited (McGlade / Ekins 2014). Concurrently – and somewhat paradoxically – massive exploration programmes are underway towards discovering and extracting new Arctic and deepwater oil resources.

As a consequence, there is a lingering fear that stock markets around the world may soon be faced with a huge 'carbon bubble' that is in danger of being abruptly deflated. According to the Carbon Tracker Initiative (2012), the world's known fossil fuel reserves (with a breakdown of 65% coal, 22% oil and 13% gas) are tantamount to five times the world's carbon budget up to 2050. At the same time, many leading stock exchanges are heavily exposed to a fossil fuel based portfolio, with 20–30% of their market capitalisation invested in fossil fuel assets. The resulting risk is immense, given that the financial robustness of the companies concerned hinges on the ability to keep exploiting their carbon assets or, alternatively, effect a rapid transition to new business models.[10] Box 12 illustrates the economic rationale of moving away from carbon-based investment strategies in the case of the Norwegian Oil Fund (considering preventive divestment) and the German utility RWE (having to act under market pressure).

Box 12: Re-evaluating carbon assets: the examples of the Norwegian Oil Fund and of RWE

The Government Pension Fund of Norway (widely known as the Norwegian Oil Fund) is among the largest sovereign wealth funds globally and owns the largest stock portfolio of any investor in Europe. Established to secure a future-proof management of receipts from the country's petroleum reserves, the Fund pursues an active investment strategy based on ethical principles and does not shy away from divestment. This became very clear in 2010 when shares held in major tobacco companies were sold. In March 2014, a broad parliamentary coalition announced a thorough review of the Fund's fossil-fuel investments, which amount to USD 44 billion or 8.4% of total investments held (Financial Times 2014a). The pointed question is being asked if ownership of carbon investments remains a sound strategy in view of prevailing climate change trends. If this divestment were to happen, it has the potential to send shock waves across the world's financial markets and trigger many institutional investors to follow suit.

Concurrently, on the part of carbon-based companies, failure to adjust to new realities is now rapidly translating into economic losses and asset devaluation. The first-ever net annual loss in 60 years reported for 2013 by RWE – Germany's largest power generating company – has made headline news. The company had to write off EUR 4.8 billion on its existing power stations. Its CEO bluntly stated that *"we were late in entering the renewables markets, possibly too late"*. While the DAX Stock Index slightly increased over the last six years, RWE shares dropped in value by two-thirds. Similarly, the French utility GDF Suez reported a 2013 net loss of EUR 9.3 billion, which was attributed to the perceived crisis in European energy markets (Financial Times 2014b). It seems that companies failing to actively adapt their strategies to sustainability requirements are now facing severe market pressure.

Necessary policy measures to counter the economic risks inherent in carbon-based assets and to incentivise fossil-based companies towards keeping their carbon in the ground have

10 However, available evidence points in the direction of widespread business as usual. Between 2011 and 2013, the level of embedded carbon at the New York stock market increased by 37% (mostly from oil companies) while at the London stock market it went up by 7% (mostly coal-based) (Carbon Tracker Initiative 2013, 4).

hardly been discussed to date. They would involve intricate issues of asset valuation, risk management and financial compensation – not dissimilar to those being discussed for the ecosystem service of maintaining rather than exploiting tropical rain forests. As a modest starting point, the monitoring and reporting of asset-embedded carbon would be a first step in this direction and could help create awareness on the part of investors, analysts, regulators and rating agencies.

Concrete examples of path disruption

The main aim of 'traditional' industrial policy is to provide infant industry protection for alternative technologies at their pre-commercial stage. Once they have matured and are able to compete in commercial conditions, it is left to market forces to decide whether and how rapidly the new industry can substitute established competitors. *Green* industrial policy is different; it also involves measures to proactively phase out undesirable technologies (Altenburg / Pegels 2012).

While we have emphasised above the massive forces of resistance against any deliberate move away from the pathways of the past, Boxes 13 and 14 provide two illustrative cases of pathway disruption in action: the Montreal Protocol aimed at phasing out ozone-depleting substances and the EU roadmap to bring down car emissions through fleet emission standards.

The examples show that phasing out is possible even against considerable vested interests, especially if realistic, binding and transparent roadmaps are defined which allow industries to adapt to the new policy frameworks and improve existing or create alternative technologies accordingly. Interestingly, both examples show that international (in the case of the Montreal protocol even global) agreements are feasible – which ensure that none of the signatory governments is tempted to undercut its neighbour's standard with the aim of gaining competitive advantages.

Box 13: Phasing out ozone-depleting substances: the Montreal Protocol success story

By their very nature, most forms of environmental damage are transboundary. Air and water pollution, depletion of fish stocks, waste transport, erosion of the ozone layer and ultimately, climate change are matters of global impact and of global concern; hence the proliferation of international environmental agreements, such as the Montreal Protocol on Protecting the Ozone Layer (1987), the Basel Convention on Hazardous Waste (1989), the Nagoya Convention on Biodiversity (1992), the Kyoto Protocol on Climate Change (1997), and the Stockholm Convention on Persistent Organic Pollutants (2001).

The Montreal Protocol is widely considered as a singular success story of global collective action towards disrupting an unsustainable pathway of industrial production (Brander 2013). Established in 1987 and ratified by 196 states and the EU, the Montreal Protocol and its four implementing agencies (UNEP, UNDP, UNIDO, World Bank) have orchestrated the phase-out of 98% of ozone-depleting substances, mostly chlorofluorocarbons (CFCs). While the challenge of phasing out Hydro-CFCs (with an exceedingly high global warming impact) remains to be solved, the success of the Protocol is attributed to a number of design and implementation factors, which at least to some extent hold lessons for other areas of collective global action.

The most significant success factors comprise: A scientific consensus on the need to act, based on the 'precautionary principle'; the limited scope of technologies involved; the availability of technologies for CFC substitution; the accepted notion of differentiated country responsibilities; the involvement of big industrial players from the private sector; and the provision of commensurate financing through the Multilateral Fund in support of developing country signatories, who were also granted longer adjustment periods.

Box 14: EU vehicle fleet emission standards

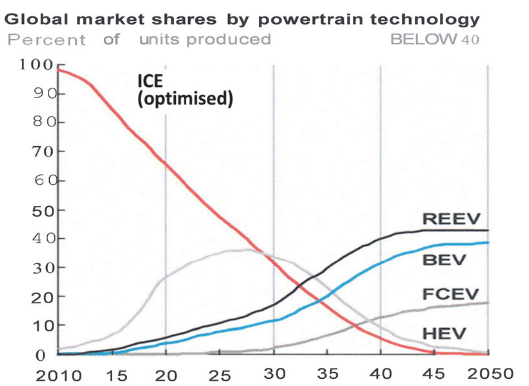
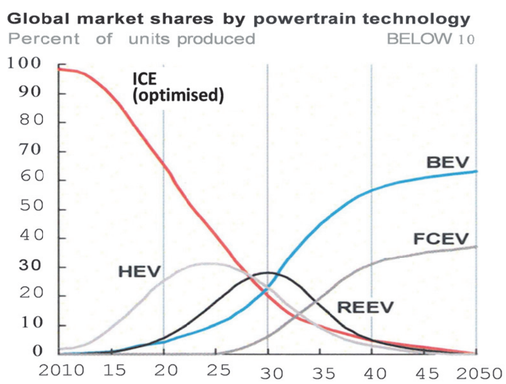
In 2009, the European Commission adopted a mandatory CO_2 emission reduction programme for the automotive industry. This was enacted in reaction to failure of the automotive industry to meet its own voluntary targets. According to the programme, each vehicle manufacturer must bring fleet-average CO_2 emissions down to 130 g/km (grams per kilometre) by 2015 and 95 g/km by 2021. The regulation is phased-in gradually: Manufacturers must meet their average CO_2 emission targets in 65% of their fleets in 2012, 75% in 2013, 80% in 2014 and 100% from 2015 onwards.

Such a roadmap creates transparency among all market actors, and it gives manufacturers time to adapt to new regulatory frameworks while providing security for the necessary investments. Compared to past incremental improvements in reducing automotive emissions the targets are ambitious, hence they do provide a regulatory push for innovation. At the same time, the targets were set on the basis of extensive consultations with industry and independent experts to ensure that they are not beyond reach and transition periods long enough to allow firms to adapt. In this regard, the standards are a good example of policy-induced innovation towards sustainability.

As many other policies, however, the CO_2 emission reduction programme has also suffered from powerful interest groups lobbying against its implementation. Particularly Germany's automotive industry, with its competitive advantage in high-powered luxury cars, played an important role, with the German government and EU parliamentarians using their political influence in Brussels to dilute the policy targets. As a consequence, heavy vehicles are allowed to emit more than light cars; low-emissions vehicles (below 50 g/km) may be counted several times when calculating average fleet emissions; and manufacturers may form pools to *jointly* meet their CO_2 emission targets (Altenburg 2014).

The example of fleet emission standards also reveals that the level of ambition of regulators can have an enormous impact on the choice of technological solutions. The graph below illustrates two scenarios for the deployment of alternative powertrain technologies, assuming moderate (below 40 gCO_2/km) and strict (below 10 gCO_2/km) fleet emission standards by 2050. In the moderate scenario, internal combustion engines are phased out slowly and technologies that combine electric motors with a conventional combustion engine (HEV and REEV) play an important role as bridging technologies. In the strict scenario, purely battery-electric and fuel-cell powertrains soon become the dominant technological design (McKinsey&Company 2011).

Scenarios of electromobility deployment under different carbon emissions targets

(A) Moderate: Fleet emissions below 40 gCO_2/km by 2050	(B) Strict: Fleet emissions below 10 gCO_2/km by 2050
	

ICE = Internal combustion engine; REEV = Range-extended electric vehicle; BEV = Battery-electric vehicle; FCEV = Fuel-cell electric vehicle; HEV = Hybrid electric vehicles.

Source: McKinsey (2011, 7)

4 The political economy of green transformation

In the preceding section, we have elaborated the salient features and challenges of green industrial policy and have done so mostly from a techno-economic perspective, that is, addressing technological and behavioural change requirements and the related economic drivers and barriers. This has already led to frequent references to resulting political conflicts and trade-offs, such as in the case of stranded carbon assets and the removal of fossil fuel subsidies.

In Section 4, we will now address the political economy of green transformation processes in greater detail before bringing out in Section 5 some key elements that need to be put in place to drive transformative change.

Managing policy rents

Our starting point is the fact that that the green transformation requires enormous upfront investments in new assets which, given the manifold market failures described earlier, need to be induced by policy; put differently, *policy rents* need to be created to make these investments ‘artificially’ attractive. At the same time, sources of profits related to unsustainable business practices need to be reduced by policy, as shown in the example of stranded assets. Creating and withdrawing rents to manage the transition to more sustainable economies is thus the most fundamental challenge, or indeed the “heart of green industrial policy”, as Schmitz / Johnson / Altenburg (2013) have put it.

In essence, the management of policy-induced rents involves the creation (respectively dismantling) of incentives that cause economic actors to temporarily generate profits above (respectively below) those the market itself would allow. This calls for complex assessments and decisions at different levels: first, it requires a clear sense of direction and purpose in terms of a longer-term economic and social vision (‘where to go’); second, it presupposes the identification of economic activities (sectors, technologies) that define the path of getting there; and third, it calls for a calibration and fine tuning of policy instruments (incentives) that establish conditions of optimal encouragement without overshooting. The obvious risk is that an overly generous provision of incentives leads to a wasteful allocation of scarce resources and triggers behavioural patterns that turn rent-seeking into the very objective of investment thus stifling the entrepreneurial drive for innovation.

At the same time, when conceptualised and implemented in an optimal manner, policy rents can be a powerful tool and have the potential to become a strategic resource for driving structural change (Altenburg / Engelmeier 2013). Energy systems in particular have always been shaped by policy rents, favouring coal-based regimes during the post-war decades, nuclear energy in the 1970s and ’80s, and renewable energy since the 1990s. The range of specific instruments is broad. Rents can be created by raising prices (such as in the case of feed-in tariffs for renewable sources of energy), providing long-term loans at preferential rates, subsidising R&D investments into specific new technologies or creating a dedicated physical or institutional infrastructure for collaborative technological exploration activities (for instance, in the form of a public-private research consortium).

Risks of political capture

The broader topic of political or regulatory capture has accompanied the industrial policy debate from its inception. It is one of the essential building blocks of the claim that government failure is always part of the equation and may be as great or even greater a risk than market failure. In essence, it asserts that powerful interest groups can influence the outcome of regulatory action by government agencies and counteract the intended purpose of incentive schemes (Laffont / Tirole 1991).

In this context, it is worth pointing out that in democratic societies, the predominant form of political capture derives from lobbying rather than straight corruption. This distinction is important as it implies that the related activities are principally legal, legitimate, transparent, open to everybody and mostly in the broader interest of entire industrial sectors rather than being firm-specific (Boehm 2007). Hence, the issue is not primarily one of business 'purchasing' political decision-makers or specific pieces of legislation. Rather, it is the gradual dilution and diversion of policy measures away from their intended goals with a view to reducing their effectiveness and impact (as shown in Box 14 for the case of automotive fleet emission standards).

For a number of reasons, the risk of rent-seeking political capture is particularly pronounced in the case of 'green' incentives systems geared towards pushing for sustainability (Altenburg / Pegels 2012). By their very nature, such incentives are (a) provided under conditions of technological uncertainty, that is, aimed at taking incipient technologies towards the threshold of commercial viability; (b) designed in an open-ended manner to cover long-term transition periods; and (c) affecting the entire economy rather than just a limited number of specific sectors. Hence, it is almost impossible to establish unambiguous causality chains and hold policymakers accountable.

The challenge of rent management is not only to create the right amount of rents to lure capital into desirable activities, but also to withdraw rents from undesirable (for example, polluting) sectors and technologies. This, again, is easier said than done. While the sunset industries left behind by the sustainability transformation are ultimately fighting a losing battle, they are still striking back with a vengeance. Whether conventional power plants, major utilities, steel industries or automotive companies, they are mobilising the powerful voice of vested interests to reduce the pace of change, water down new regulations and lobby for exemptions – thus allowing them to keep extracting profits from their conventional lines of business.

Both, the uncertainty about the future and the incumbent's vested interests make green incentives a worthy target for lobbying campaigns and put the responsible government agencies under heavy pressure to stay their policy course. Obviously, the ability to resist such pressure is generally low in contexts of poorly developed government capabilities, weak monitoring systems and insufficient transparency, in other words under conditions prevailing in many low-income countries. However, as Box 15 illustrates, even mature industrial economies are prone to political capture.

Box 15: Electricity surcharge in Germany: exceptions becoming the rule?
The much-heralded German Renewable Energies Act established the principle of providing feed-in tariffs (over a 20-year period) for renewable sources of electricity generation. The costs originating from guaranteed prices above market rates are translated into an electricity price surcharge to be borne by all consumers of electricity, including both households and manufacturers. Hence, the result is a deliberate policy-induced rise in electricity costs. However, the law also foresees the possibility of exemptions for particular types of companies. This is exactly where political capture kicks in. Such exemptions were initially confined to manufacturing enterprises with high energy intensity (electricity cost of at least 14% of production value) and subject to international competition, such as steel and chemical industries. Meanwhile however, exemptions have proliferated and cover a broad range of diverse industries not foreseen under the provisions of the law. As a result, the sum total of exemptions grew from 7% of Germany's electricity consumption in 2004, to 20% in 2014. In 2014, the number of companies exempt from the electricity surcharge jumped to more than 2,000, representing a 22% increase over 2013. Clearly, initially well-defined and justified exemptions have become subject to aggressive lobbying leading to a level of political capture that erodes the very credibility of the incentive itself. In late 2013, the EU Commission opened an in-depth investigation of the compatibility of the exemptions with EU state aid rules. Early 2014, the German government reformed the eligibility rules slightly, but without touching the total exemption sum of about EUR 5.1 billion per year. Experience with the European Emissions Trading Scheme (ETS) shows that political capture does not only happen at individual state level. Various authors claim that the European ETS has fallen prey to a mix of vested interests of various lobby groups advocating the free allocation of permits ('grandfathering'), exemptions and loopholes, and the excessive issue of permits, contributing to what Helm (2009a, 26) calls the *'climate change "pork barrel*"' (Betz / Sato 2006; Helm 2009b; Helm 2010; Spash 2010).

While the debate on unburnable carbon is gaining traction (see Sub-section 3.4 above), countries worldwide are continuing to pump massive amounts of subsidies into fossil fuels. These are both environmentally harmful and distributionally regressive. Box 16 illustrates the political difficulties of subsidy reform efforts.

Box 16: Reforming fossil-fuel subsidies
A global consensus has been reached that fossil-fuel subsidies pose substantial constraints to the sustainability transformation process (Beaton et al. 2013; Clements et al. 2013). Worldwide consumption subsidies reached USD 544 billion in 2012, and production subsidies add USD 100 billion per year (IEA 2013b). This level of spending is exceedingly high given that, for every dollar spent on renewable energy technologies, six dollars are spent on fossil-fuel subsidies (IEA 2013b). Moreover, many countries commit approximately 5% of their GDP (gross domestic product) to fossil-fuel subsidies (Dobbs et al. 2011). While fossil-fuel subsidies are justified by policymakers on equity and competitiveness grounds, there is mounting evidence showing that continuing to pay such subsidies has adverse social, fiscal, and environmental effects. In particular, fossil-fuel subsidies have been benefiting middle- and upper-income population groups, and other powerful stakeholders – such as energy-intensive industries and fuel distributers. Moreover, fossil-fuel subsidies have contributed to market distortions to the detriment of renewable energy, energy efficiency and green growth. For these reasons, reforming fossil-fuel subsidies requires complex interactions between the society at large, state, business sector, energy producers, as well as international donors. Strong vested interests among these stakeholders, and even within the government, trigger multifaceted political economy dynamics. Given that reforming fossil-fuel subsidies would involve withdrawing (and redistributing, that is, better targeting) rents, none of these groups has much interest in changing the subsidy regime.

Box 16 (cont.): Reforming fossil fuel subsidies
Where reforms were implemented in the past and have been considered successful, coalitions among stakeholders were formed, compensation schemes implemented and extensive information campaigns carried out (for example, South Africa, Turkey, Philippines). In these countries reform was depoliticised by setting up independent agencies for energy policy, ensuring stability and consistency of reforms. At the same time, improved macroeconomic conditions and transparency in decision-making reduced opposition to reform and the need for large compensation packages, and contributed to coalition building. In most cases, however, reforms fail due to lack of state capabilities to manage strong opposition from interest groups, lack of public awareness on the size and impact of subsidies and inability to form consensus among diverging interests (for example Mexico, Egypt). Here, political fragmentation (coupled with high instability in the case of Egypt) and centralised decision-making process on energy pricing, were key deterrents to reform (Vidican 2014). Further, even with a targeted safety net and a commitment to sound macroeconomic policies in place, the Mexican reform failed due to lacking information campaigns and transparent accounting of subsidies (Clements et al. 2013).

In view of the high incidence of political capture and powerful forces retarding transformative change as illustrated above, the question arises as to which institutional conditions and economic incentives can be created with a view to minimising the likelihood of political capture. We will turn to this issue in the following section.

5 Ways forward: changing direction – directing change

The previous sections have revealed the enormous complexity and context-specificity of the green industrial policy challenge. Successful transformation requires ‘greening’ at various levels, from people’s norms and values to changes in political institutions, from innovations at the level of households, firms and value chains to changes in mechanisms of global governance. The good news is that innovations at these levels are often mutually reinforcing: Positive feedback loops may exist between new information and communication technologies, global knowledge networks and consumers’ environmental awareness; new technological options may drive more ambitious regulations, and vice versa; scientific insights and pioneering applications may inform new, more sustainable development narratives, etc. Understanding how such co-evolution unfolds, who and what drives it or obstructs it, is the basis for accelerating change towards sustainability.

In charting the course towards a green transformation we highlight some particularly important elements: A broad social *consensus on the direction of change* and the related long-term objectives is critically important. This needs to be underpinned by multi-stakeholder *change alliances* and complemented by openness to *systematic policy learning*. Finally, a *transparent policy process* is essential to avoid political capture. Essentially, this calls for putting safeguards in place that allow for a close alignment of politically set incentives with evolving new markets.

Wanted: A broad-based social contract

As elaborated above (see Sub-section 3.2), green industrial policy is implemented within a context of both high uncertainty and long-time horizons. Ideally, this would call for a societal consensus on a long-term vision, a path to transit to agreed goals, an acceptance of the costs of policy incentives (both in terms of subsidising sunrise sectors and compensating sunset sectors) and above all, the eventual distribution of these costs. However, if experience in both mature industrialised and developing countries is anything to go by, a social contract of this nature will remain elusive. Economic and social reality is inevitably characterised by winners and losers and hence by conflict and controversy based on often irreconcilable objectives of different societal groups. This renders a consensus on specific policy approaches and instruments highly unlikely. Yet what it does not preclude is agreement on a long-term vision or even on closing down certain options, as for instance in the German decision to exit from nuclear energy. As mentioned above in Sub-section 3.2, there is often an element of ‘endogeneity’ at work, for instance, when long-term policies in favour of renewable energy change entire markets, bring down prices and create profit opportunities for future investments.

What is needed then may not be a full-blown political consensus but rather a broad agreement that establishes a sufficient degree of policy ‘directionality’ (Mazzucato 2013). Such a consensus, as argued by the German Advisory Council on Global Change, would foster a culture of attentiveness to long-term sustainability goals, a culture of democratic participation and a culture of responsibility for future generations (WBGU 2011, 2).

New ways of measuring social welfare would be an important foundation for underpinning a consensus on long-term goals. GDP as the most widely used proxy is incompatible with a green growth paradigm. While attempts are needed to develop agreement around new welfare indicators, in most countries there is an almost paradoxical disconnect between green transformative goals on the one hand and their continued measurement by conventional economic indicators on the other hand. There are numerous conceptual attempts to move away from the fixation on GDP rankings but this has not yet been translated into action. One such conceptual innovation is being championed by the World Economic Forum with the Sustainable Competitiveness Index (WEF 2012b), which complements a narrow notion of economic competitiveness with two additional dimensions, namely social sustainability (measured, for example, by access to health care, income inequality and levels of youth unemployment) and environmental sustainability (measured, for example, by the enforcement of environmental regulations, forest depletion, levels of air pollution and CO_2-intensity).[11]

Forging a consensus on the most promising transformative technologies, institutions and metrics – as well as identifying their economic and social impact – is a formidable task. It cannot be reasonably addressed without highly complex negotiations between the full spectrum of stakeholders ranging from government agencies to business, trade unions, consumer organisations, civil society and the research community – representing a quintessential example of ‘embedded autonomy’ (Evans 1995). A concurrence of multiple factors is critically important. In addition to cooperative global governance structures (which we do not address in this paper), this presupposes reliance on the available knowledge base, involvement of transformative change agents, as well as a proactive state willing to establish a framework for transformation and push for green innovation (WBGU 2011, 6).

11 Two illustrative examples show the significant impact of new approaches to measurement: By moving from economic to sustainable competitiveness, for example, the rank of the United States drops from 6 to 17. Similarly, when applying another new indicator, the Inclusive Wealth Index (UNU-IHDP / UNEP 2012), the 1990–2008 annual *per capita* growth rate of China is lowered from 9.6 to just 2.1%.

Transformative change alliances: the role of co-benefits

As argued throughout this paper, the green transformation is a 'project' involving exceedingly high levels of ambition, uncertainty and complexity. Requiring resources as diverse as knowledge, finance and credible leadership *"no single actor has the resources to bring about the green transformation"* (Schmitz, forthcoming). The dynamics at work are co-evolutionary – involving changing norms and values, innovation towards new general-purpose technologies, policy experiments and changing power constellations. Such a scenario gives rise to unconventional alliances. As emphasised by research on actor-centred institutionalism (see, for instance, Scharpf 1997), there are considerable flexibilities and spaces for individuals to push innovation even in well-established institutions. This applies particularly in situations where institutions are faced with fundamental changes in their operating environment and have not yet developed coherent and enforceable response strategies thus putting a premium on innovative action. As a result, there is a great potential for change alliances across conventional boundaries. For instance, the German energy transition has been driven by civil society advocacy groups with a genuine green agenda; enlightened business circles anticipating the growth of green markets; employers *and* trade unions alike in sectors benefiting from new jobs (such as in wind and solar energy) or in electronic and chemical industries exporting specialised components to green industries worldwide; and regional governments and municipalities seeking to strengthen decentralised power (sic!) structures. While such heterogeneous change coalitions are difficult to organise and often operate in loosely connected networks, *"the chance of effective cooperation increases dramatically if players with different motivations are brought into the picture"* (Schmitz, forthcoming).[12]

Strong emphasis on the co-benefits of green growth is often key to mobilising the positive forces that can push for transformative change. Indeed, such co-benefits are manifold and range from triggering innovation, competitiveness and the creation of green jobs (ILO / UNEP 2012; ILO 2013) to the positive health impact of improved air quality, enhanced energy security and less waste generation (for a comprehensive account of the 'climate bonus', see Smith 2013). An effective green industrial policy must build on these co-benefits from its inception (see Box 17). They form the foundation for unconventional alliances that are critically important for political advocacy campaigns. In this context, emphasising social inclusion and fairness is key. Only if and when the necessary burden-sharing of the green transformation is perceived as equitable by various population segments, will it be possible to sustain support in the long run.

Box 17: Co-benefits of green growth in developing countries
IPCC (2014) defines co-benefits as the positive side effects that result from implementing mitigation policies and measures. The size of co-benefits depends on a variety of factors, such as the level of renewable energy technology deployment, existing technological capabilities, and state capacity to develop and implement coherent long-term strategies. Measuring and capturing co-benefits from green growth can impact investment decisions, individual behaviour as well as the priority setting of policymakers (IPCC 2014, 42).

12 *"In many highly conflictual negotiation situations the discovery of previously unknown 'win-win solutions' may make all the difference between a policy impasse and effective action"* (Scharpf 1997, 63).

Box 17 (cont.): Co-benefits of green growth in developing countries
IPCC groups co-benefits into economic (e.g. energy security, local employment, irrigation, flood control and water availability), social (e.g. contribution to energy access, health impacts), and environmental (e.g. decrease in air pollution and water use). Other ways in which co-benefits could manifest themselves, especially relevant for developing countries, are technology transfer, industrial development, upgrading of domestic technological capabilities, reduction in volatility to the price of fossil-fuels, and improved livelihoods conditions at the household level. While some of these effects are more difficult to quantify, their long-term effects and economic spillover impacts can open up new corridors for development. Aside from job creation (widely discussed in the literature), one of the key indicators of progress in least developed countries (LDCs) is the level of access to modern energy services. The WHO and UNDP (2009) estimate that 79% of LDC population lacked access to electricity in 2009, compared to a 28% average in the developing countries. For LDCs from sub-Saharan Africa and parts of Asia, with limited access to fossil-based electricity, large-scale deployment of off-grid solutions based on clean energy technologies is critical for fuelling their development process and shifting to more sustainable agriculture (Guruswamy 2011). Rural electrification, in turn, can generate other benefits, such as educational improvements (Kanagawa / Nakata 2008). Yet, for developing countries, the success of energy access programmes has to be measured against affordability and reliability criteria for the poor (IPCC 2014, 46).

Employment effects of green growth have been crucial in this regard. While most of the green jobs are being created in OECD countries and in emerging economies like China and Brazil (UNEP 2008), there is also evidence of positive employment effects in low-income developing countries. Aggregate medium-term estimates by the Asian Development Bank (ADB 2013) expect that up to 2% of the entire Asian workforce will be employed in green jobs – with greater impact in low-income countries due to their high above-average dependence on forestry and agriculture.

Systematic policy learning

Arguably, industrial policy is more an art than a science. It is highly contextualised and requires the skilful combination of instruments adapted to the prevailing economic and social conditions as well as the institutional capabilities of a particular country. After many years of standardised, orthodox policy prescriptions (as quintessentially codified in the 'Washington Consensus'), there is growing recognition today of the creative potential that can be unleashed through heterodox policy innovation and experimentation. To a great extent, this new policy paradigm is based on the rise of emerging economies (the BRICS and beyond), which *inter alia* has been the result of applying unconventional policy approaches that combine market forces with state leadership. With China being the prime example, even the notion of a new 'Beijing Consensus' has been suggested (Cooper Ramo 2004).

This openness towards experimentation is particularly pronounced in attempts to shape future sustainable development patterns. For instance, model cities experimenting with new low-carbon infrastructures are spreading in emerging economies and explore new forms of energy-efficient buildings, public transport, infrastructure for scaling up the use of electric vehicles, or waste recycling.[13] In the absence of homogeneous and binding global environmental policy

13 It is noteworthy that – contrary to widely held beliefs – Chinese CEOs are even more concerned about climate change than the global CEO average. Specifically, according to a PriceWaterhouseCoopers study, one third of all CEOs surveyed in China (including Hong Kong China) consider climate change

frameworks, international networking and knowledge-sharing among pioneers of change – for example 'clubs' of cities with a green transformation agenda, international networks of environmentally conscious CEOs, NGO networks – can make important contributions in terms of developing and testing sustainable alternatives and increasing their appreciation in society (WBGU 2014).

Allowing for systematic policy learning is thus crucial – both in terms of learning from effective and successful policy instruments applied in other countries and in terms of learning over time. Box 18 illustrates approaches to adapting and improving policy instruments with emphasis on the concept of a 'learning spiral'.

Box 18: Policy learning – concept and practice

The complex nature of the green transformation process (involving high uncertainties and risks, synergies and trade-offs between goals and outcomes, and different but highly interconnected actors) requires a policy process able to respond to these challenges. More than 40 years ago, Schön (1973, 28) claimed that in response to higher uncertainty modifying institutions is not enough; rather "*we must invest and develop new institutions which are 'learning systems', capable of bringing about their own continuing transformation*."

The need for such an approach could not be more pressing today. Systematic policy learning, we argue, must have two main dimensions: learning from others as well as learning over time. Further, cycles of learning should be put in place, where reviews and revisions of goals and achievements are regularly carried out. The implications that such an approach has on policy actors is not trivial, as it requires a shift from policy-making based on linear thinking to one based on complex adaptive systems (Hallsworth 2012).

Several studies have recently explored how to achieve an effective policy process when dealing with complex problems (Jones 2011). One of the most compelling approaches to integrate learning in policy-making is the 'learning spiral' developed by the World Bank based on several theoretical and practical concepts (Blindenbacher 2010). At its core is an iterative process based on feedback loops that allows the integration of new knowledge in the decision-making process and adds flexibility to revise earlier goals and objectives in order to ensure adaptability to a continually changing reality. Another important element is the 'learning broker' or facilitator, in charge of framing the knowledge, facilitating the ongoing revision, moderating the interactive learning procedures, and facilitating dissemination of new knowledge. Along such learning spirals several policy-making tools need to be used to enhance learning (from others and over time), such as horizon-scanning, scenario-planning, technology foresight exercises, value-chain analyses, systems mapping and growth diagnostics.

An example of what such a policy-making process could look like in practice is the National Platform for Electromobility (Nationale Plattform Elektromobilität, NPE), a joint council of the German government established in 2010 (Vidican et al. 2013). NPE includes representatives of industry, academia, government, trade unions and civil society and pursues "*a systematic, market-focused and technology neutral approach with the aim of developing Germany into a lead provider of and a lead market for electromobility by 2020*" (NPE 2010, 5). NPE comprises seven working groups, each in charge of an issue relevant to electric mobility. The work of NPE is coordinated by its steering committee (playing the role of a learning broker), which comprises the leaders of each working group and representatives of the German government. The fact that a wide set of interests are represented ensures that compromises are sought and a joint strategy pursued. Following a series of consultation processes, analyses, and foresight exercises, NPE publishes a yearly interim report with up-to-date recommendations for strategic action at various different levels and for various different actors. These reports form the basis of choosing development pathways able to respond to fast-changing market conditions and technological progress.

to be a major risk factor for their business – as compared to only 27% in the global survey (Association of Chartered Certified Accountants 2012).

Box 18 (cont.): Policy learning – concept and practice

According to the latest report of the NPE, Germany is unlikely to reach its envisioned target of one million electric vehicles by 2020, unless the monetary incentives of the government's programme are revised (e-Mobility NSR 2012), continuous cross-technology cooperation is pursued, and roadmaps for a systemic approach to the development of the sector are developed. Yet, significant achievement have already been made in the preparatory phase by following an integrated approach that brings together so far unlinked areas such as transport and the energy sector (NPE 2012).

At the same time, 'learning from others', in particular learning from 'Southern' approaches has so far hardly taken place in industrialised countries. One specific field that lends itself to such policy-learning is the smart use of feed-in tariffs. While conceptualised in the context of rich economies, the tool has also come to be applied widely in emerging economies. Considerable experience has been gained with various auctioning schemes (see the general assessment in Box 19 and the specific case of India in Box 20).

Box 19: Promoting renewables through feed-in tariffs: learning from the South

'Reverse auctioning' (also referred to as 'reverse bidding' or 'reverse tendering') schemes – while often presented as a policy instrument *sui generis* – can actually be considered a possible complement to FiT (feed-in tariffs) schemes allowing for tariff levels to be determined in a competitive manner, that is, testing the market before granting subsidies. Apart from the United Kingdom, they have been applied primarily in emerging economies such as China, India, Brazil and South Africa. In actual implementation (for instance for wind energy projects in China and Brazil, for solar projects in India and for various renewable energy technologies in South Africa), the overall impact has been positive with the principal drawback having been a high incidence of 'frivolous' bidding: investment proposals that were deliberately underpriced and not followed through once approved. This has led to introducing safety mechanisms such as bidding fees and potentially high penalties to be paid (India) or awarding contracts based on the average bidding price rather than the lowest bidding price (China).

With the diversified experience gained and lessons learnt in these emerging markets, designing an effective auctioning scheme could be a promising option for reforming FiT systems that in some European countries (notably in Germany) have not been as cost-effective as initially expected. It would also constitute an intriguing case of exporting a policy scheme and, in time, re-importing its improved version (Lütkenhorst / Pegels 2014).

Box 20: Smart policy design – India's National Solar Mission

India has a huge energy deficit. In 2009, over 400 million people were not connected to electricity grids. Moreover, power cuts cost an estimated EUR 39 billion per year. Even more worrisome, things are not getting better: Over the past 30 years, the gap between electricity generation and consumption has widened and increasing fossil fuel imports constitute a huge financial burden for the country.

At the same time, India has an enormous potential for solar energy: The country enjoys, on average, 300 sunny days per year and receives an hourly radiation of 200 MW/km^2. However, the cost of electricity generated from solar installations is high, at EUR 0.27/kWh (2010) compared to about EUR 0.09/kWh retail grid parity and EUR 0.04/kWh coal-based generation cost. As India is a country of overwhelmingly poor energy consumers, the willingness and ability to pay higher electricity prices for environmental reasons is low. In fact, most state utilities are even unable to collect sufficient electricity fees to cover the generation costs of coal-fired power plants, and consequently run huge deficits. Moreover, fuel and electricity are strongly subsidised, which makes it even more difficult for renewable energy to compete. In 2010, as a result, India's solar electricity generation was negligible, at 0.1 GW compared to an overall electricity generation capacity of 177 GW.

Box 20 (cont.):	**Smart policy design – India's National Solar Mission**
In 2012, India enacted its National Solar Mission with the aim of ramping up capacity of grid-connected solar power generation from 0.1 GW to 20 GW, plus 2 GW off-grid, by 2022. At the same time, costs should be brought down to retail grid parity by 2022. Given the existing cost differential and the manifold structural problems of India's energy market, how could this be achieved? Based on the National Solar Mission, India in fact managed to leverage huge investments in solar power plants. Within just two years, installed capacity went up from 0.1 to 1.5 GW; at the same time, the cost of solar energy was brought down through a highly effective competitive reverse auction: In late 2011, the central regulatory authority auctioned solar power projects offering a 25-year feed-in tariff. The feed-in tariff however was not set at a fixed rate (as, for instance, in Germany) but auctioned, awarding a limited number of projects to those project developers who proposed to work with the lowest tariff. The auction was carried out in several rounds and batches, starting with a number of small projects to set the market and adapting the conditions from one round to the next. The number of submitted bids was enormous, and the competition brought tariffs down quickly. While before the auction, a feed-in tariff of EUR 0.27/kWh was considered to be the minimum to operate a photovoltaic power plant, the second auctioned batch already brought the average bid down to EUR 0.14/kWh. To prevent interested parties from submitting low bids to win contracts but then failing to fulfil them, bidders have to provide bank guarantees, which are drawn in case of delayed project development. Despite the low tariffs, the reverse auctions triggered such big investments that installed solar power capacity increased from 0.1 to more than 1 GW within only 18 months. Hence the National Solar Mission, with its clearly defined targets, its sequenced approach and in-built safeguards, was highly successful in terms of mobilising investment *and* bringing tariffs down. Given these unexpectedly low bids, the Government of India now expects solar electricity to reach retail grid parity as early as 2017, five years earlier than initially foreseen by the National Solar Mission (Altenburg / Engelmeier 2013).	

Furthermore, with the huge uncertainties and risks involved in green industrial policy, there must be commensurate demands on efficient and transparent implementation as well as tight monitoring. Roadmaps based on inclusive technology foresight exercises and coupled with feedback mechanisms are as important as the regular performance measurement of institutions accountable for implementing policy programmes. While this applies generally, it obviously gains particular importance in contexts of weak institutional capabilities, corruption-prone administrations, pervasive market failures, and neopatrimonial rule (Altenburg 2013) where checks and balances are needed to disentangle and evaluate different policy functions.

Aligning green industrial policy with market mechanisms

Throughout this text we have highlighted the importance of public policy in guiding the search for more sustainable forms of economic activity. However, this does not imply a return to old concepts of state-led economic development. The green transformation requires creativity and an accelerated rate of innovation, in terms of technologies as well as institutions. Economic history has shown the importance of the private sector in creatively developing commercially viable solutions for a wide range of problems – in some case without major government support but more often, as Mazzucato (2013) has recently shown, with quite substantial public investment at precompetitive stages. The conventional debate, which tends to juxtapose the state with the market, is as stale as the stereotype of picking winners. The art of industrial policy in general, and green industrial policy in particular, is to find agreement on the broad direction of desirable societal change and incentivise the private sector – through regulatory guidance and rent management – to use its creativity accordingly.

Many of the examples provided throughout the text have underlined how competitive market-based mechanisms and private sector initiatives can be built into policy design and implementation. The more this is actually done, the smaller will be the remaining space for turning policy incentives into private gains. Specifically, this may involve:

- Building competitive bidding into feed-in tariff approaches (see Boxes 19 and 20).
- Basing the adoption of green norms and standards (or voluntary agreements) on proposals coming from the private sector (Box 9 and UNIDO 2011c, Ch. 6) and coupling such proposals with performance standards and binding time lines to be determined by public policy.
- Encouraging the private sector to adopt voluntary standards and recurring to mandatory regulations only when self-regulation fails (see Box 15 for the example of automotive fleet emission standards).
- Using the most resource-efficient product developed by the private sector to determine the standard, which other products within the same product category have to achieve within a specified time-span, as applied in Japan's 'top-runner programme' (BMUB 2008).
- Enhancing market transparency through exposing carbon footprints or other environmental 'bads' in product labelling.
- Promoting new standards, as actually done by the International Standards Organization, in the field of environmental accounting and management (UNIDO 2011a, Ch. 5).
- Opening up technology promotion incentives to competition coming from regional innovation clusters.
- Testing new sustainable technologies in public-private collaboration schemes based on cost-sharing arrangements.

Green industrial policy recognises the primacy of politics over economics, but it can also build on market-driven and private-sector led search processes to achieve its targets. Creative new ways of collaborative public-private policy design are required, following the principle of *embeddedness* of public agencies in market processes, combined with *autonomy* in decision-making to avoid political capture (Evans 1995).

6 Conclusions: from shared goals to coherent policies

In the preceding sections, we have highlighted the characteristic features of green industrial policy and provided illustrative examples of some of its real world challenges. It is now time to pull together the main arguments and arrive at some general conclusions.

In essence, the green transformation is not happening as an autonomous, market-driven process. It reinforces the primacy of public policy – requiring the readiness of an active green industrial policy to question the main pillars that past development processes have rested upon.

As we have argued, this translates into an essentially normative discourse. Correcting market failures in the form of environmental externalities is necessary, yet not sufficient. Green industrial policy inevitably deals with long-term visions and goals of societies. It has a particularly strong normative content. Neglecting this primacy of norms, their social context of complex stakeholder negotiations, old vested interests as well as new transformative alliances, can only come at the cost of irrelevance.

The Herculean task ahead calls for a fundamental rethinking of the prevailing growth model; the reliance on resource-efficiency and carbon footprints as new metrics and allocation criteria for sustainable development; new behavioural patterns and consumption priorities; radical technology innovation ranging from new renewable energy technologies to redesigning entire transport and mobility systems; and political agreement on how to allocate the remaining global carbon budget.

There is no doubt that uncertainties and risks are exceedingly high, and some wrong choices are likely to be made. This is why a rational and transparent policy process, continuous and systematic policy learning, and options for corrective action are of greatest importance. We would submit however, that the ultimate risk is associated with not acting at all in the face of possibly catastrophic environmental and climate scenarios.

We have also seen that the social acceptance of green industrial policies is essentially related to their distributional impact, in particular in terms of affecting the balance between green sunrise and brown sunset industries. The same applies to the impact on different population groups, which is one of the reasons for the continued prevalence of fossil-fuel subsidies. Yet, while debates on growth and inequality as well as growth and environmental damage have taken place for many decades, the necessary debate on the synergies and trade-offs between green and inclusive growth has been largely missing so far. Indeed, the relationship between the green and the social pillars of sustainable development has remained under-researched, thus leading to the widespread use of lofty declarations in lieu of hard evidence.[14]

Solutions for a green transformation are country-specific and will require a high degree of contextualisation. In some cases, norms and values may change first and then drive policy and technology innovations. In others, new technological options may be in the lead and exert a strong pull. Also, in many cases the economic opportunities associated with emerging green markets will trigger the build-up of new sources of competitiveness and provide new foundations for forward-looking employment creation.

Ultimately, the choice facing policymakers is between reactive change (necessitating *ad hoc* and costly responses to environmental crises) and proactive change (relying on a politically managed process). To be sure, in the face of uncertainty and uncharted policy territory, the latter is no guarantee for *not* making mistakes along the way. But then, as James Joyce pointed out, *"mistakes are the portals of discovery"*.

14 Often, the issue is buried in the definition itself by positing that *"a green economy can be thought of as one which is* ***low carbon, resource efficient*** *and* ***socially inclusive****"* (emphasis in original) (http://www.unep.org/greeneconomy/AboutGEI/WhatisGEI/tabid/29784/Default.aspx).

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